LUCIFER

User Manual

Distribution List

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Document Change Record

Issue	Date	Sect./Paragr. affected	Reasons / Remarks
0.1	11/26/07	all	new document
0.2	01/11/08	all	minor changes
0.3	03/28/08	3.1.9, Appendix B	added/changed filter curves
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1.0	11/20/09	All	Update before release
1.1	12/24/09	Tab. 8	Corrected full well
		Tab. 12	Corrected Ks ZP
		6.6.2, 7.2.2, 7.3	Updated with more information
1.2	08/03/10	6.6.2	New paragraph about tellurics for MOS masks
		7.2	New section included
		7.5.2.	Description of MOS acquisition procedure added
		all	minor changes (typos, ...)
1.3	03/05/10	7.3.3, 7.4	Added information about archive parameters
		all	Clean tables and figures caption for the table of content

Note: Chapter 5 fully related to LBT issues has been written by Dave Thompson from LBTO.

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1 Acronyms

AO	adaptive optics
ADC	atmospheric dispersion corrector
AGw	acquisition, guiding & wavefront sensing system
DARK	dark current
DIT	detector integration time
NDIT	number of detector integration time
FIMS	FORS Instrument Mask Simulator
FOV	Field of View
FPU	Focal Plane Unit
LBT	Large Binocular Telescope
LMS	LUCIFER Mask preparation Software
LUCIFER	LBT NIR Spectroscopic Utility with Camera and Integral Field Unit for Extragalactic Research
RON	readout noise
wfs	wavefront sensor

2   Introduction

LUCIFER (**L**BT NIR Spectrograph **U**tility with **C**amera and **I**ntegral-**F**ield Unit for **E**xtragalactic **R**esearch) is a NIR spectrograph and imager for the Large Binocular Telescope (LBT) working in the wavelength range from $0.85\,\mu$m to $2.5\,\mu$m. Currently only one LUCIFER instrument is available at the LBT. It is mounted on the bent Gregorian focus of the SX mirror. In 2011 an identical instrument will be mounted on the bent Gregorian focus of the DX mirror (i.e. other side of the telescope). The observing modes currently available are

- seeing-limited imaging over a $4'$ field of view (FOV)

- seeing-limited longslit spectroscopy

- seeing-limited multi object spectroscopy with slit masks

As soon as the adaptive secondary will be operational at the LBT, following additional observing modes will exist:

- diffraction-limited imaging over a $0.5'$ FOV

- diffraction-limited longslit spectroscopy

Spectroscopic observations can be carried out with a resolution of up to 17,000 (seeing limited) and 40,000 (TBC - diffraction limited). The instruments are equipped with Rockwell HAWAII-2 HdCdTe 2048×2048 px^2 array.

3   LUCIFER

3.1   Instrument description

Figure 1 shows the optical layout of LUCIFER.
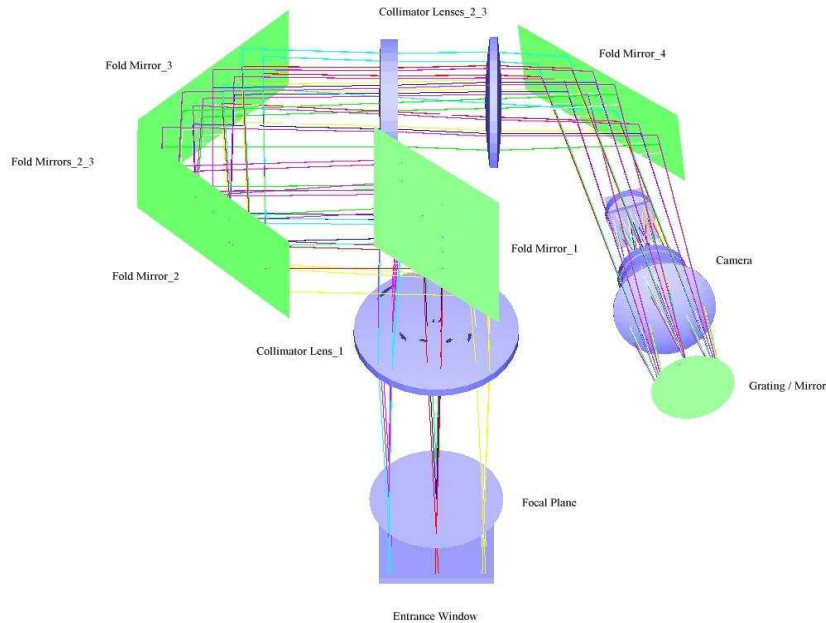
Figure 1: LUCIFER optical layout

The wavelength bands covered by the LUCIFER optics include z, J, H and K, i.e. the range from 0.85 to 2.5 μm. In practice however the observing range is limited on the blue side by the cut-off wavelength of the entrance window (0.87μm, section 3.1.1) and on the red side by the cut-off of the atmospheric window after 2.4μm.

The main observing modes are summarized in Tab. 1 and Tab. 2.

Table 1: LUCIFER's imaging modes

Camera	N1.8	N3.75	N30 (non available yet)
Scale ($''$ / pixel)	0.25	0.12	0.015
FOV (arcminute)	4×4	4×4	0.5×0.5
Comments			FOV limited by isoplanatism

Table 2: LUCIFER's spectroscopic modes. LSS stands for Long Slit Spectroscopy and MOS for Multi-Object Spectroscopy.

Camera	N1.8	N3.75	N30 (non available yet)
Scale ($''$ / pixel)	0.25	0.12	0.015
FOV (arcminute)	4×2.8	4×2.8	0.5×0.5
Resolution (2pix)	1900 … 8500	3800 … 17000	10000 … 40000
Comments	LSS & MOS	LSS & MOS	LSS
	full coverage zJHK		

3.1.1 Entrance window

The instrument entrance window is tilted by 15° in order to reflect the visible light to the on-axis wavefront sensor (for adaptive optics). The current entrance window has a blue cut-off wavelength at 0.87 μm, as illustrated in Fig. 2.
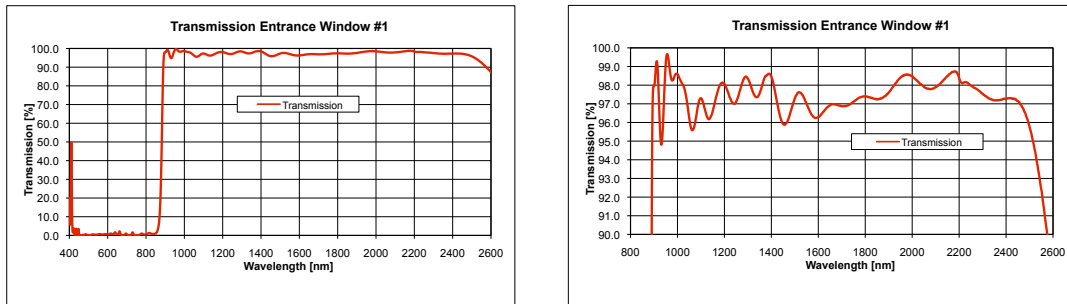
Figure 2: Transmission curve of the LUCIFER #1 entrance window. The plot left shows the overall transmission (inclusive the "leak" around 400nm), while on the right a zoom over the NIR range is presented.

3.1.2 Focal Plane & Slit Masks

The useful unvignetted field of the telescope is $\varnothing \sim 7'$. The layout of the optics for the seeing limited case covers a field of $4' \times 4'$ ($144\,\text{mm} \times 144\,\text{mm}$). The focal plane, commonly refered to the FPU (Focal Plane Unit), can be equipped with masks for long-slit and multi-object spectroscopy as well

as field stop mask. Up to 33 masks are available inside the instrument, out of which up to 23 can be exchanged, without warming up the instrument.

The multi-object mode of LUCIFER offers the possibility of obtaining spectra of several objects simultaneously. The masks used for this mode are custom made laser cut masks.

The LUCIFER multi-slit masks are made from 125 μm thick stainless steel from ThyssenKrupp, chemically blackened on one side. The coating has been tested at LN2 temperature and in a laser cutting machine. MPE supplies this material for the mask cutting machine at LBT. The sheet thickness has been optimized for the LUCIFER mask frames. No other material should be used to avoid problems with stability and warping of the masks during cooldown.

The masks do not exactly follow the focal surface because they are cylindrical. The cylinder radius is that of the focal surface (1033 mm), and the shape is defined by the mask frames. the cylinder axis is in dispersion direction, therefore, the defocus is constant along a standard (not inclined) slit. The defocus can be limited to ±0.5 mm for the central area of 4 armin height and 2.5 arcmin width in dispersion direction. The limitation to this central area is sensible, because spectral clipping by the detector array increases with increasing distance of the slit from the field center.

The exchange of masks is a daytime operation that needs about one week to be prepared:

- mask cutting (at LBTO in Tucson)

- the newly cut masks sheets have to be installed in frames, that have to be put in the cabinet that will then be inserted in LUCIFER.

- the auxiliary cryostats one empty to receive the cabinet currently in LUCIFER and the other one containing the newly filled cabinet of masks to be inserted, have to be cooled down

On the day of the exchange, the empty cryostat is attached to LUCIFER. A bridge vacuum seal is pumped, the exchange gate is then opened and the currently used cabinet of masks is moved out of LUCIFER. Thereafter the gate is closed, the vacuum bridge put back to atmospheric pressure so the auxiliary cryostat can be detached from LUCIFER. The operation is then repeated with the other auxiliary cryostat, the one containing the new set of masks. After the exchange, at least one auxiliary cryostat has to be warmed up to remove the cabinet it contains and receive new masks. There is thus a minimum of a week between 2 cabinet exchanges. At the moment, cabinet exchange are foreseen once per month with the goal before each new block of science runs.

A software tool, the LUCIFER Mask Simulator (LMS), has been made available to prepare masks for multi-objects spectroscopy and is presented in section 6.1.2.

Permanent masks   A set of masks is permanently installed in LUCIFER. These masks are meant either for instrumental calibration or long slit spectroscopy. These include some sieve masks used essentially to measure flexures and internal field distortion, a blind mask to take dark frames, a set of long slits and a mask thought for spectrophotometric calibrations. These masks all have a fix mask-ID, which is indicated in the Table 3 as well as the current position of these masks in the mask's cabinet.

3.1.3   Collimator

The refractive collimator with a focal length of 1500 mm is used in all modes. The resulting collimated beam size is 102 mm. The collimator includes 4 flat folding mirrors. The last of those mirrors is motor-driven and used for the instrument internal flexure compensation.

Table 3: Permanently installed masks

Mask Name	Mask-Number ID	Position in cabinet NB	Remarks Reference for scripts
Optic Sieve	990063	0	array of pinholes (for imaging & N3.75 camera)
Spectro Sieve	990001	1	pinhole array for spectroscopic calibrations
Closed/Blind	990031	3	used for darks measurements
LS 600	990034	4	$1.00''$ slit
LS 450	990029	5	$0.75''$ slit
LS300Nblack	990078	6	$0.50''$ slit - sampling limit N1.8
LS 150	990065	7	$0.25''$ slit - sampling limit N3.75
3_slit	995623	8	3 centered vertical slits of $10''\times30''$ for spectrophotometric standards
LS 300	990032	9	Currently not usable

3.1.4   Gratings

The grating unit holds one mirror (for the imaging mode) and 3 gratings. The (laboratory) measured efficiencies of the gratings are presented in Appendix B. Additionally, the main characteristics are summarized in Tab. 4.

The difference in peak efficiency between the diagrams in Appendix B (manufacturer data) and the values given in Table 4 is due to the fact that the gratings are used in non-Littrow configuration in LUCIFER.

Order	λ_{peak}[μm]	Max. Efficiency [%]	50 % Cut on [μm]	50 % Cut off [μm]	Resolution
		High resolution grating with 210 lines/mm			
2.	2.44	68	2.02	3.18	6687
3.	1.64	77	1.41	1.90	7838
4.	1.24	76	1.09	1.41	8460
5.	1.00	72	0.89	1.11	6877
		H+K grating with 200 lines/mm			
1.	1.87	83	1.38	>2.40[1]	1881 (H)/ 2573 (K)
		Ks grating with 150 lines/mm			
2.	2.13	78	1.81	>2.40[1]	4150

Table 4: Characteristics of the gratings. The resolution is given for the N1.80 with 2pixel sampling at the peak wavelength.
[1]: The 200_H+K and 150_Ks grating do not have a cut-off within our wavelength range.

The gratings can be tilted in order to center a selected wavelength at the position of the long slits. Table 5 defines the wavelength range covered for the tilt at the nominal central wavelength.

The gratings can individually be tilted by up to ±2.5 degrees. This allows a range of wavelengths to be centered on the detector as given in Table 6 for the N1.80 camera.

Note: the 150_Ks grating can presently not be tilted and is fixed at $\lambda_{cen} = 2.15\mu$m.

Grating	Band	λ_{min}	λ_{cen}	λ_{max}	$\Delta\lambda$
210_zJHK	K	2.025	2.200	2.353	0.328
210_zJHK	H	1.541	1.650	1.743	0.202
210_zJHK	J	1.169	1.250	1.319	0.150
210_zJHK	z	0.893	0.960	1.017	0.124
200_H+K	H+K	1.475	1.930	2.355	0.880
150_Ks	Ks	1.890	2.170	2.423	0.533

Table 5: Wavelength coverage for the gratings with the N1.80 camera at the nominal center wavelength. For the N3.75 camera multiply $\Delta\lambda$ by 0.48.

Grating	Band	λ_{range} (μ)
210_zJHK	z	0.87 ... 1.02
210_zJHK	J	1.05 ... 1.28
210_zJHK	H	1.40 ... 1.70
210_zJHK	K	2.10 ... >2.4
200_H+K	OrderSep	1.49 ... >2.4

Table 6: Wavelengths which can set at the center of the detector. **Careful:** the ranges given represent the physical limits of what can be achieved with the grating tilt and does not take into account the limits of the filters used for order separation.

3.1.5   Pupil Viewer

In combination with the N1.8 camera, a pupil viewer is realized which allows to check the pupil image for vignetting and inhomogenous illumination. Two lenses have to be added to the beam: one in front of the camera, the other one is placed in one of the positions of filter wheel #1. (Fig. 3) presents a current pupil image of LUCIFER. Because of the structure of the one-armed swingarm support, the diffraction spikes are not standard. The LBT PSF has an asymmetric 10-armed diffraction pattern, rather than the usual 4-arm from typical spiders.

The displacement of the pupil to its stop causes presently a light loss of about 17%. This will be corrected during the next warm-up of the instrument.

3.1.6   Cameras

N1.8   This camera is designed for seeing-limited spectroscopy for covering one single broad band (z, J, H or K). The image scale of this camera is 0.25 $''$/pixel. The maximum distortion is less than 0.1 % within the 4 arcmin field. It can also be used for imaging in seeing limited mode, but bear in mind that the lateral color is not corrected.

N3.75   It is dedicated for both seeing-limited imaging and seeing-limited slit spectroscopy. The image scale of this camera is 0.12 $''$/pixel. In spectroscopic mode it covers about half of the zJHK bands wavelength range at higher resolution (for an equivalent slit width defined in pixel compared to the N1.80 camera).

N30   This camera (0.015 $''$/pixel) is intended to be used for diffraction-limited imaging and longslit spectroscopy, together with the adaptive optics. The sampling of this camera is optimal for the FWHM$_{\text{Airy}}$ of the J band (2.0 pixel). The H and K bands are oversampled (2.73 pixel and 3.73 pixel respectively). It is currently not available.

The available modes are also given in Tab. 1 and Tab. 2.
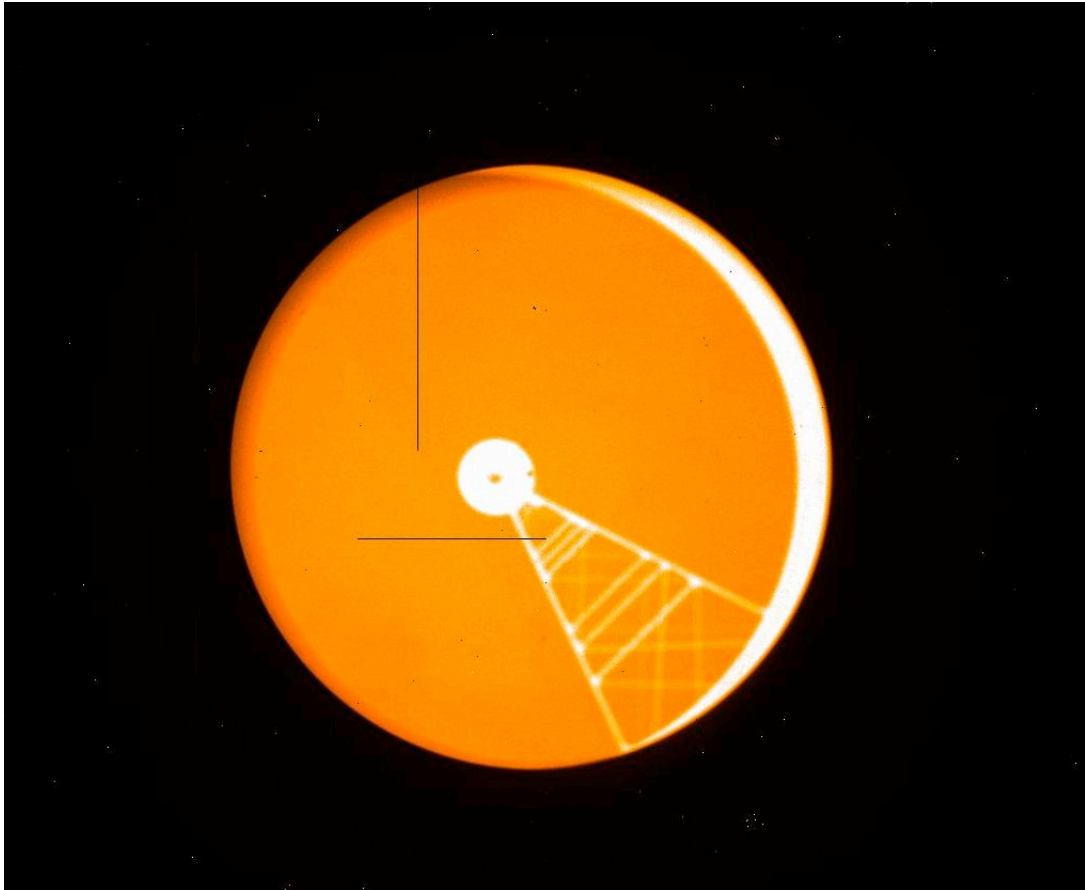
Figure 3: LUCIFER pupil image in K band. On this image the swing arm sustaining the secondary mirror is visible (PA=160deg), as well as the displacement due to an internal pupil mis-alignment.

3.1.7   Filters

Two filter wheels are placed in the convergent beam in front of the detector. A total of up to 27 filters can be mounted. The first filter wheel contains the narrow and medium band filters as well as a pupil viewer, while the second wheel contains all broad band filters and the order separation filter (for spectroscopy with the 200_H+K grating). Both filter wheels contain a blind filter. Filter wheel #1 is always set before filter wheel #2 starts moving. This is important to remember when wishing to avoid saturation e.g. before long spectroscopic integrations. The characteristics of the currently available filters in LUCIFER #1 are given in Tab. 7.

Appendix C contains details about the manufacturing specifications of the filters (Tab. 19), an equivalent of Tab. 7 with the filters for LUCIFER#2 (Tab. 20) as well as all the transmittance curves (section C.1).

3.2   Detector and Acquisition System

Characteristics
   The detector is a HAWAII-2 HdCdTe detector, whose main characteristics are summarised in Tab. 8.

Readout Modes

Table 7: Characteristics of the filters installed in LUCIFER #1.. The position indicates in which filter wheel (FW) the filter is installed.

Name	LUCIFER	Position	$\lambda_C/\mu m$	FWHM/μm	τ_{peak}	$\tau_{average}$
z [3002]	1	FW2	0.957	0.195	98.4 %	94.3 %
J [0403]	1	FW2	1.247	0.305	91.2 %	83.2 %
H [4302]	1	FW2	1.653	0.301	95.0 %	90.5 %
K [3902]	1	FW2	2.194	0.408	90.1 %	85.7 %
K_s [3902]	1	FW2	2.163	0.270	90.7 %	86.8 %
Order Separation [ED763-1]	1	FW2	1.950	0.981	95.0 %	86.3 %
Br_gam [Brackett-γ (ED477-1)]	1	FW1	2.170	0.024	79.4 %	76.5 %
FeII [(ED468-1)]	1	FW1	1.646	0.018	91.2 %	89.5 %
H2 [(ED469-1)]	1	FW1	2.124	0.023	87.9 %	84.9 %
HeI [(1085-15)]	1	FW1	1.088	0.015	65.2 %	64.6 %
J-high	1	FW1	1.303	0.108	95.9 %	93.3 %
J-low	1	FW1	1.199	0.112	95.4 %	93.3 %
OH_1060	1	FW1	1.065	0.009	68.6 %	66.8 %
OH_1190	1	FW1	1.193	0.010	80.4 %	78.0 %
P_beta [Paschen-β (ED476-1)]	1	FW1	1.283	0.012	86.1 %	85.5 %
P_gam [Paschen-γ (ED467-2)]	1	FW1	1.097	0.010	81.1 %	80.0 %
Y1	1	FW1	1.007	0.069	67.3 %	64.2 %
Y2	1	FW1	1.074	0.065	94.2 %	89.5 %

The channel layout is shown in Fig. 4. Channels are numbered along the fast direction, starting with quadrant I. The read-modes offered are:

- **DCR (double correlated read mode):**

  This mode is the default in high background applications, where background limited performances are reached easily.

  The detector is first reset then read-out. Reading of the detector is always non-destructive. After the selected integration time, the chip is read-out again.

  The difference of the two read-out frames removes detector, channel and pixel specific properties which are present in both frames, and preserves the integration charge value.

  The 'o2' of the o2dcr mode stands for some additional line clocking after the frame reset, which were necessary for most HAWAII-2 detectors tested for Omega2000, to get rid of strange ramps

Table 8: Characteristics of the detector

Pixelsize	18.0 μm^2
Number of pixels	2048×2048 pixel^2
Fullwell	~ 260000 e$^-$
Linearity	better than 5% at 80% full well
Quantum efficiency	z=0.25, J=0.33, H=0.74, K=0.73
Readout mode	Double-Correlated Reads (DCR)	Multiple-Endpoint Reads (MER - fixed at 10 samples)
Min Exposure time	2sec	10 sec
Gain	4.083 e^-/ADU	3.93 e^-/ADU
RON	< 12 e$^-$	< 5 e$^-$
DC	0.06 e$^-$/s/pix	(0.06 e$^-$/s/pix), to be confirmed
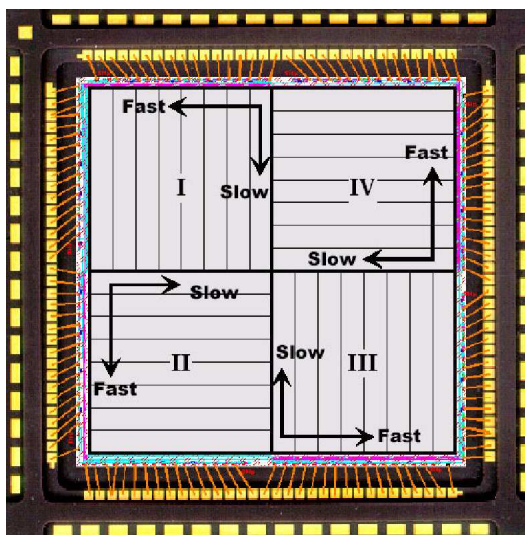
Figure 4: Detector Layout. The arrows indicate how the four quadrants are read and which is the direction of the slow & fast reads.

in the first frame, to enable correct data reduction.

- **MER (multiple endpoint read mode):**

  This mode, also called Fowler sampling, reduces the read noise by the square root of the number of reads and has a better cosmetic than DCR for a given integration time. It is particular well suited for faint objects observations (either imaging with narrow band filters or spectroscopic long integrations).

  A number of reads is performed after the reset, and the same number of reads is performed after the integration time. The signal is the average of the difference of always 2 endpoint samples (Fowler-pair), all pairs have the same double-correlated integration time.

  The number of samples for the offered mode has been fixed to 10 endpoints, which is equal to 5 Fowler pairs (compromise between reduced noise and increased minimum integration time).

  (mer mode of Lucifer is based on the o2dcr mode with the same additional clocking after the frame reset to prevent problems with the first frame.)

Figure 5 illustrates how the currently offered LUCIFER readout modes work.

Figure 6 shows a typical LUCIFER dark frame, where some known artefacts are highlighted. The two main nasty features are a bad column at x=[783,784] for y=[1025,2048] and a bad line at y=[859,861] over the x range of [670,1025]. As much as possible avoid putting any of your spectrum over the area. The central line/column (1024,1024) of "dots" are some features of the DCR readmode. They nicely disappear in difference images, however do not put an object in view of taking its spectrum perfectly in the middle of the detector (in Y).

Note: Unlike most infrared detectors, the LUCIFER detector is read only upon request = there is no permanent reads on-going.

3.3   Calibration Unit

This unit can be moved in front of the entrance window. Three arc lamps (Neon, Argon and Xenon) are available for wavelength calibration and three halogen lamps for flat fields.

Note that moving the calibration unit in front of LUCIFER obstructs the light coming from the telescope, thus guiding will not be able to continue while internal calibrations are being taken over
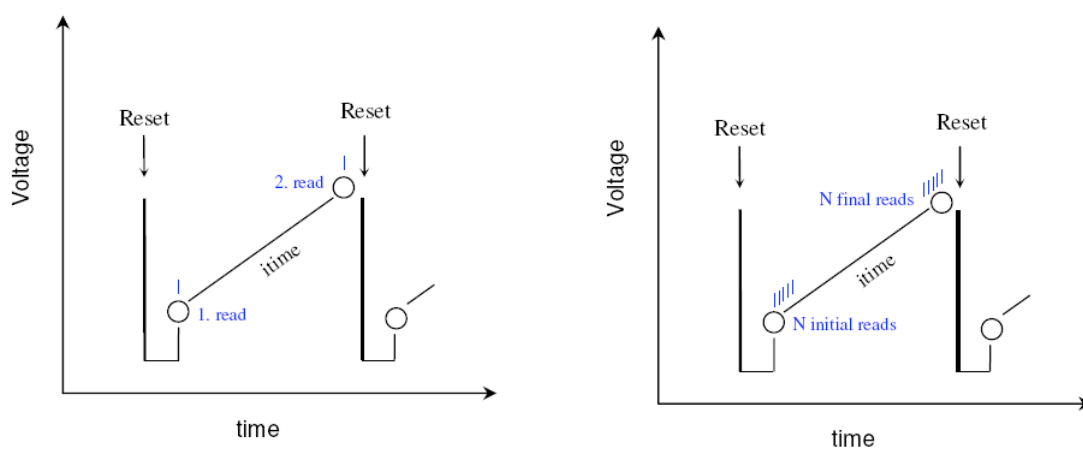
Figure 5: Illustration of the way the LUCIFER readout modes work: DCR to the left, MER to the right.
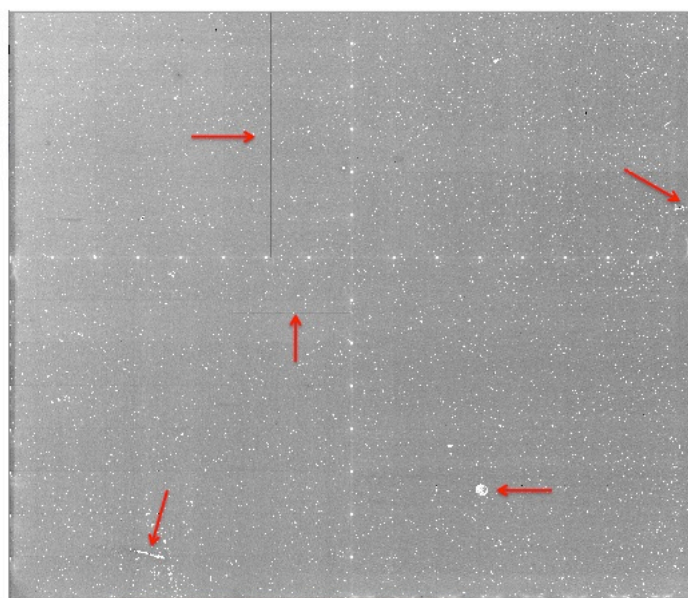
Figure 6: Part of a LUCIFER image, where few features (bad column/line and few bad pixel clusters) have been highlighted.
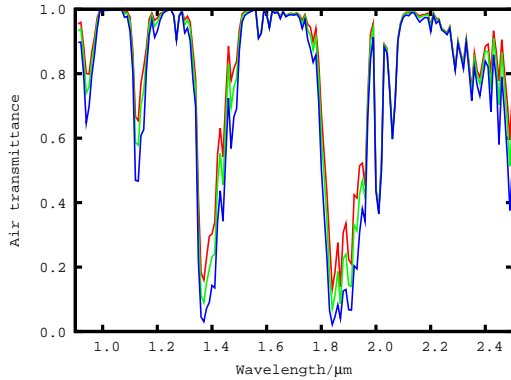
night. In this case, ask the telescope operator to pause guiding and active optics corrections for you, before the calibration unit is moved in the light path.
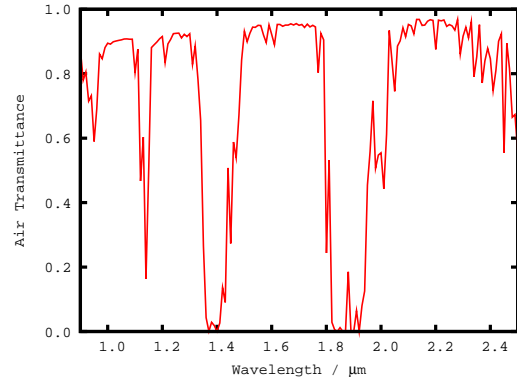
4   Observing in the NIR

4.1   Atmospheric Transmittance

The water vapor in the atmosphere is the leading cause for absorbing light in the near-infrared. The transmission of light for three different water-vapor levels in the wavelength range from $0.9\,\mu m$ to $2.5\,\mu m$ is shown in Figure 7(a). This plot is a model atmosphere for Mauna Kea. The plot 7(b) shows the mean transmittance of an atmospheric model for the 2MASS site. The location of 2MASS is on Mt Hopkins (about $60\,km/40\,miles$ south of Tucson, AZ).

(a) The air transmittance for Mauna Kea and three different water-vapor levels: $1.0\,mm$ (red), $1.6\,mm$ (green), $3.0\,mm$ (blue)

(b) The mean air transmittance for the site of 2MASS north (Mt. Hopkins) which is located about $150\,km$ (ca. 100 miles) southwest of the LBT.

Figure 7: Transmittance vs. wavelength for Mauna Kea (a) and Mt. Hopkins (b).

4.2   Background Emission

The near-infrared sky spectrum measured from the ground at a typical observing site is shown in Fig. 8. These lines are well known and can be used for wavelength calibration in spectroscopic mode. Below $2\,\mu m$ the night sky emission is dominated by OH and O_2 airglow emission. Unfortunately, the intensity varies about $5\% \text{-} 10\%$ due to changes in local density of OH, over timescale of the order of $5 \text{-} 15$ minutes. Above $2\,\mu m$ thermal emission from the atmosphere and from the telescope dominates the background radiation.

4.3   Imaging

Jitter

In classical NIR broad-band imaging the signal of the sky background is much higher than the one from the objects. Additionally, it's intensity can vary considerably on timescales of minutes. Jitter imaging takes care of that issue with a minimum loss of observing time. For each exposure one observes the same region on the sky with different small offsets around a central position. The sky background emission can then be determined from the jittered frames if the local field is neither too crowded nor too dusty or will have to be estimated from sky frames obtained away from the region of interest and observed before and/or after the science field.

4.4   Spectroscopy

Nodding

In spectroscopy the object of interest is observed at different positions along the slit (=nodding
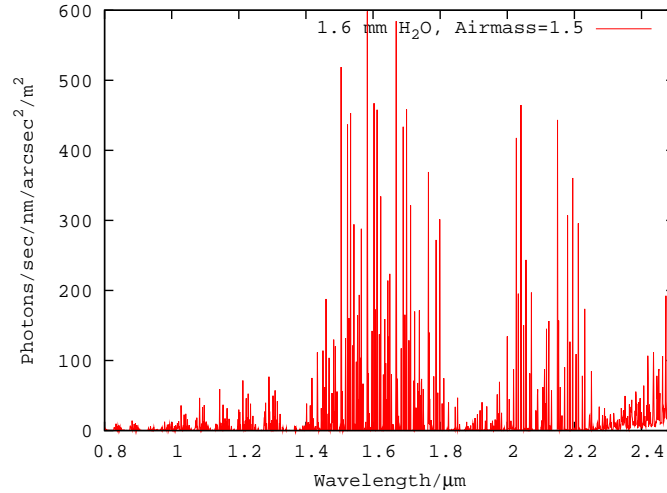
Figure 8: Sky spectrum measured at Mauna Kea

along the slit). The sky removing is then simply done by substracting two different frames from each other.

For small size objects observed in long slit spectroscopy mode, it is recommended to keep the nod size $\leq \pm 30''$ to avoid being affected by the curvature of the atmospheric lines. This is just to ease your data reduction.

Wavelength Calibration

Below $2.2\,\mu\text{m}$ OH lines can be used for wavelength calibration. Above that wavelength the OH lines are very weak. In that case it is recommended to use the arc lamps of the calibration unit (3.3).

4.5   Influence of the Moon

Observing the near-infrared, the influence of the Moon illumination is small and can in many cases be ignored. However for deep imaging (long integration of faint objects) at short wavelengths (e.g. in z band), the increased sky illumination may need to be taken into account.

The Moon illumination is however a problem for the guiding system, which works at optical wavelength. It is therefore recommanded to avoid observing closer than 30 degrees from the Moon, to avoid possible contamination effects on the wavefront sensor of the guider system.

5   Observing at the LBT

5.1   Introduction

The Large Binocular Telescope uses an azimuth-elevation mounting. Two 8.4 meter diameter primary mirrors are mounted with a 14.4 meter center-to-center separation. Some basic characteristics are summarized in Table 9.

The LBT is unlike every other major telescope in that the design is highly asymmetric. The primary mirrors are cantilevered off a central pair of elevation C ring bearings. These elevation C rings have extensions that support one-armed A-framed swing arms that allow the secondary and tertiary mirrors, as well as the prime-focus cameras, to swing into or out of primary mirror optical axis. The primary (M1) and secondary (M2) mirrors are mounted on hexapods that allows them a considerable range of

motion (± 3 mm for M1, ± 10 mm for M2) in six axes. The tertiary (M3) has a smaller range (± 1 mm) and only four degrees of freedom. It is this adjustability that will allow the LBT to operate efficiently as a fully binocular telescope.

Table 9: Basic characteristics of the LBT

effective primary aperture D_{Tel}	8251 mm
focal length f_{Tel}	123421.4 mm
effective system focal ratio N_{Tel}	15.0
primary spacing	14417 mm center-to-center
image scale	0.59836 mm/arcsec
$\varnothing$ FOV	$7'$
field curvature r_{Tel}	1043 mm
AO System	Secondary Mirror

The effective primary aperture of 8.251 meters in the table above is the area on the primary seen from the instrument because the slightly undersized secondary mirror is the pupil stop of the telescope optics. The telescope focal length and image scale were determined by tying astrometric solutions on sky (arcsec/pixel) to the scale of the precision sieve mask (mm/pixel) in LUCIFER.

There is currently a rigid secondary mirror installed on the SX side, used for seeing-limited observations. The first adaptive secondary mirror, to be installed on the DX side, is scheduled to enter operation in late 2010.

5.2   Pointing & Collimation

The LBTO maintains models for both the pointing and collimation of the telescope, the goal of which is to deliver to the wavefront sensor (wfs) a sufficiently collimated image that it can converge to a well-collimated system in a few cycles. The pointing model corrects for deviations of the real telescope from a "perfect" mechanical model, such as a tilt of the azimuth axis off zenith or flexure of the telescope "tube" as a function of the elevation. The collimation model corrects low-order optical aberrations (e.g. coma, focus, and astigmatism) as a function of elevation and temperature.

However, the pointing and collimation models are strongly coupled by temperature effects on this asymmetric telescope. As of writing (Nov 2009) this is understood as unmodeled physical offsets of the optics induced by changes in temperature or temperature gradients. These offsets in the position of the telescope optics generate offsets to both the pointing and the collimation of the telescope. Since collimation corrections from the wavefront sensor are applied in a pointing-free manner, we are left with a net change in the pointing. These thermal effects are under active investigation at the LBTO. Until this is completed, there are some steps that must be manually executed to achieve the overall initial collimation and pointing of the telescope, and maintain it throughout the night.

Pointing correction
   Note: At the start of the observing night, a check of the pointing is always necessary.

How to check and correct the pointing if necessary (Fig. 9):

1. Be sure to have the telescope operator reset the mount encoders each day before the beginning of the night.

2. Set up LUCIFER for imaging through a narrowband filter since the pointing stars are quite bright (R 7.5 mag). We usually use the N3.75 camera and the Brackett gamma filter

3. Point to a pointing star (accurate positions and proper motions) in open-loop <u>TRACK</u> mode, the rotator mode set to <u>PARALLACTIC</u>, and with an angle of zero. This aligns the LU-

CIFER detector with the telescope elevation axis (up-down on LUCIFER) and perpendicular to this (left-right on LUCIFER). A list of pointing stars is available at the telescope in the IRTC notebook, and the corresponding stars are in a catalog on the LUCIFER computer `TargetsCoord/PointingStars.tab`. The stars to use are named WT10_* or ACT*

4. Take a 2.0 second exposure with LUCIFER. At this point you can iterate this step, allowing the telescope operator to manually correct any gross focus errors until that is not the dominant collimation error, then

5. Ask the telescope operator for the current values of IE and CA. Also measure the approximate centroid of star on the LUCIFER image (x_{star}, y_{star})

6. Calculate the offset needed to move the star to the projected mechanical rotator center, currently at pixel (x_{ref}, y_{ref})=(1014,1043) as follows:

$$CA_{new} = CA_{old} + 0.12 \times (x_{ref} - x_{star})$$
$$IE_{new} = IE_{old} + 0.12 \times (y_{ref} - y_{star})$$

Please note that this reference position may change slightly after each new installation of the instrument at the telescope. Current values will always be available in the LUCIFER image headers in the keywords CRPIX1 (x_{ref}) and CRPIX2 (y_{ref})

7. Ask the telescope operator to implement these new values of IE and CA

8. Take another 2.0 second exposure to verify that the pointing star is indeed placed at the reference coordinates to within a few pixels

There is currently no user-friendly tool to perform this simple operation.

Monitor the guide star offset from the wfs on the acquisition images during subsequent presets. Whenever the guide star is more than halfway to the edge of the acquisition image you should consider repeating the above pointing correction procedure outlined above. Please keep in mind that the more out of thermal equilibrium the telescope is, the more often this will need to be repeated. On well-equilibrated stable nights you may only need to do this correction once after the beginning of the night.

Collimation   Once the pointing has been corrected, the guide stars should be within the capture range of the acquisition, guiding, and wavefront sensing (AGw) system that will be used to correct any remaining collimation errors in the telescope and maintain collimation throughout the night. Any large focus offset at the start of the night should be manually removed by the telescope operator during the initial pointing correction (above). This will deliver an image to the AGw that can be guided on while the wfs collimates the telescope.

You may select any star for this initial collimation, including an off-axis guide star at your first science target. If the telescope is far out of collimation at the beginning of the night, or the seeing is poor (> 2 arcsec), a brighter star ($R\ 10 - 12^m$) would be useful until the point where it is saturating the guider or wavefront sensor. A list of Persson infrared standards is available at the telescope in the IRTC notebook, and the corresponding stars are in a catalog on the LUCIFER computer `TargetsCoord/PerssonStds_2010.cat`. The stars to use are named BS91*. These are well-distributed over the sky, so one should be reasonably near your first science target.

Once the telescope is collimated, meaning that the rms wavefront error has converged to something below 400nm, the collimation model will normally keep you close to decent collimation even on large slews of the telescope. Difficulties can be found on nights with very poor seeing (>3 arcsec), very low winds (<2 m/s), or large temperature swings. The poor seeing affects collimation because the entrance aperture to the wfs is three arcsec in diameter, so poor seeing makes it difficult to find the centroids in each subaperture. Conversely, very good seeing should yield rms wavefront errors well
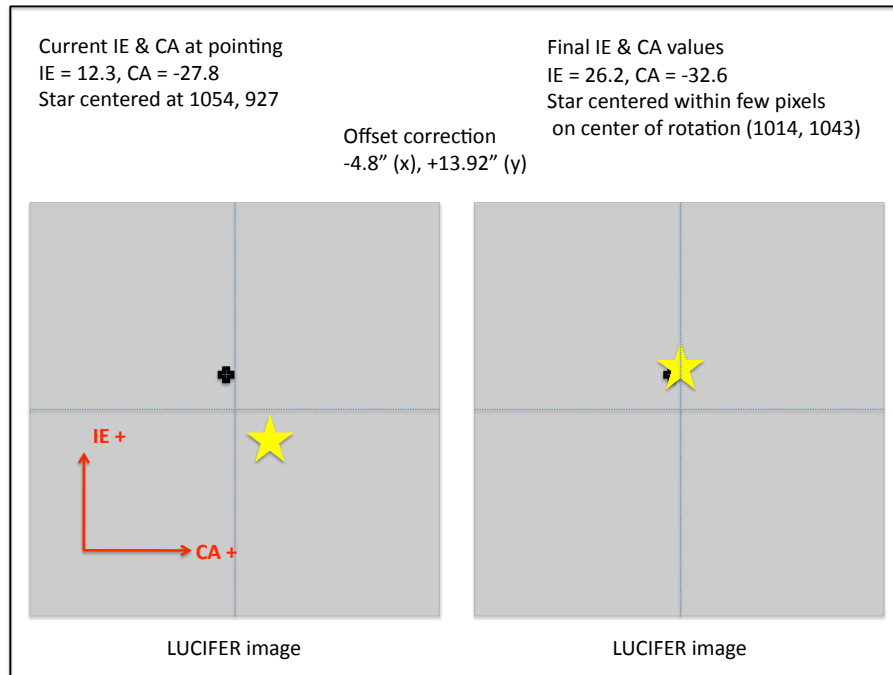
Figure 9: Illustration of the pointing correction method.

below 400nm. Low wind speeds do not flush out the dome air, so you can get "dome seeing" effects. (Effect of large temperature changes have already been discussed.)

Low order collimation corrections are applied by physically moving the optics of the telescope. In some conditions M1 can hit one of its (software) travel limits. If this occurs, you must stop observing and ask the telescope operator to recover from this.

Please keep in mind that with its very fast primary mirror (f/1.14) the LBT is very sensitive to changes in the positions of the optics, so open-loop collimation noticeably degrades in a few minutes. It is thus far more desireable to operate in closed-loop, which is defined as ACTIVE mode. The standard collimation cycle takes a 30 second exposure on the reference star to average over atmospheric effects. The whole cycle (integration, readout, processing, application of wfs corrections) currently takes ~45 seconds. Because the wfs integration cannot be interrupted, we recommend that observers set up their observations to have a dwell time at each dither position of 60 seconds to ensure that a collimation update is applied frequently. With dwell times under 60 seconds you can fall into a mode where the dithers are out of sync with the wfs cycles and you do not get collimation updates. The main caveat here is that with faint guide stars and/or poor seeing the wfs may have to use longer exposure times to have sufficient signal to collimate. In such cases, the dwell times will need to be increased correspondingly.

5.3 Guiding

Because of the way the telescope software interface was built, it is necessary for observers to come prepared with pre-selected guide stars suitable for their intended science targets. Thus, it is important to provide a guide star suitable for both guiding and wavefront sensing. This is a function of the seeing and transparency, of course, but the nominal range for guide star R-band magnitudes is $12^m.0 - -16^m.0$. The USNO-B1 catalog is a useful resource for locating guide stars and can be found at this URL:

http://www.nofs.navy.mil/data/FchPix/cfra.html

Because LUCIFER is bolted to the Auto-Guiding and (slow) Wavefront sensing (AGw) unit, they co-rotate to follow the sky, so the AGw has a fixed patrol field (Fig. 10) with respect to the LUCIFER field of view. Also, the (AGw) unit is built onto an R-theta stage, which affects the layout of the guide star patrol field with respect to LUCIFER and therefore the position angles for your observations. There are a few basic constraints to keep in mind:

1. The guide probe can move on axis, but not past it
2. The guide probe theta stage limits the X motion of the probe
3. The focal plane is blocked at >330 arcsec radius
4. There is vignetting from M3 at field angles above ~3.5 arcmin off axis
5. To avoid vignetting LUCIFER, keep the probe > 1 arcmin from the field edges

Some details:

1. The probe always appears to come down from above the LUCIFER field of view, independent of position angle on sky, because LUCIFER and the AGw are bolted together.

2. The R-theta stage pivot point is 612 mm above the center of the LUCIFER field. Limits at ±18 degrees restricts the motion to just inside the usable focal plane at the left-front bent Gregorian focus. So you need to be careful when using guide stars at high field angles and position angles that put them near these limits.

3. The focal plane delivered by the telescope is blocked by parts of the AGw at field angles of more than 330 arcsec radius.

4. The tertiary mirror is a bit undersized and there is some vignetting visible in the wavefront sensor at high field angles (>3.5 arcmin). While the wavefront sensor algorithms have been adjusted to account for this, selecting guide stars inside a radius of 240 arcsec from the science target would be better than those outside.

5. The probe emits thermal radiation and appears bright in the K band, and at all wavelengths it shadows the LUCIFER entrance aperture when close to on axis. The apparent size of the probe is 2 arcmin across, or about half the LUCIFER field of view. If this will cause problems for your project, you need to be careful in the selection of your guide star and the orientation of the field for your observations. Odd shadows or emission on LUCIFER are likely from the guide probe.

Under fully closed-loop operations (ACTIVE mode) where the same guide star is used at two offset positions in the patrol field, the positioning accuracy of the source in the LUCIFER field of view is completely governed by the guide stage accuracy of motion. In repeated tests, we achieve ~50 mas rms in the X direction on LUCIFER and ~30 mas in Y.

5.4   Open-loop tracking stability

Please keep in mind that the telescope will deliver the best image quality under closed-loop ACTIVE mode operations. It is in your best interest to set up your observations with an appropriate off-axis guide star. The additional overheads of starting up the ACTIVE mode observations are small (a few seconds) compared to TRACK mode. However it is possible, and may be desireable, to perform rapid observations in TRACK mode, such as obtaining spectra of telluric standards where neither the precise positioning nor collimation is strictly necessary. These objects are typically bright and only a few minutes are needed to take a pair of spectra. In TRACK mode, you are fully subject to any thermally-induced drifts in the pointing, so it is likely that you will need to at least make one coarse correction of the telescope position to place your target at the required location on the LUCIFER detector.
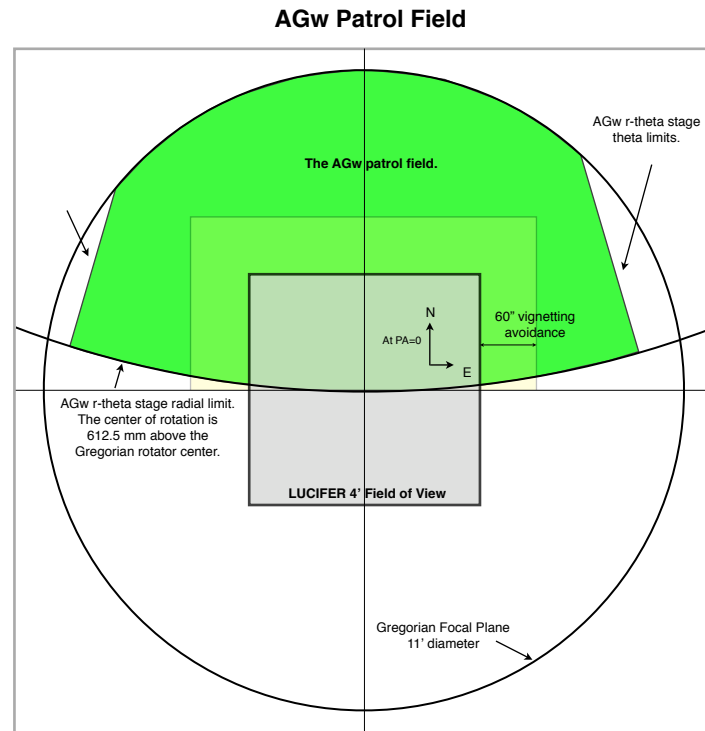
Figure 10: Plot of the AGw guide probe patrol field (green) is shown, relative to the 4'x4' LUCIFER field of view (gray square) and the delivered focal plane at the left-front bent Gregorian focal station (outer 11 arcmin diameter circle). The AGw patrol field co-rotates with LUCIFER, so it is always 'above' in detector space but would, for example, be oriented to the west of the science target at a position angle of 270 degrees.

6   Preparing observations with LUCIFER

6.1   Available tools

6.1.1   Exposure Time Calculator (ETC)

A LUCIFER exposure time calculator has been made available and can be reached at:
http://www.lsw.uni-heidelberg.de/lucifer-cgi/calculator/calculator.py
It should be used to prepare your observations and estimate the needed integration time for your
purpose.

6.1.2   LUCIFER Mask Simulator (LMS)

LMS is an observer support tool for the preparation of LUCIFER MOS mode observations.

The following is a short overview, and by no means sufficient to run LMS. Before using the program,
please read the LMS user manual carefully.

This software tool is used to:

1. set the instrument configuration (camera, grating, filter),

2. set the default slit parameters (slit type, width, length),

3. select reference stars (for telescope pointing and rotator angle offset correction),

4. select guide stars (for telescope guiding in one or more pointings),

5. position MOS slits (manually on a source image, on the source centroid using a centering routine,
   automatically on a target list)

LMS requires two input files:

- The ISF (instrument summary file) containing the relevant telescope and instrument parameters.
  This file is part of the LMS package.

- A FITS image or source catalog. The image can be taken with LUCIFER or any other instru-
  ment. Within LMS images and catalogs can be downloaded from several servers.

LMS displays the following items, as illustrated in Fig. 11:

1. FITS image or catalog positions projected on the LBT image plane,

2. when the mask "mode" is initialized:

   (a) the LUCIFER field (white square),

   (b) the back projection of the detector on the LBT image plane (blue square),

   (c) central field of low defocus (inner white lines),

   (d) field of unclipped spectra (inner blue lines),

   (e) area of the reference slits (red rectangle close to the northern edge of the mask)

3. when the mask is initialized and labeling is on (default) in addition:

    (a) rotation angle and telescope pointing in the upper left corner,

    (b) position of the six reference slits

    (c) calculated wavelengths limits on the array at the two southern corners

    (d) central wavelength at the northern edges of the unclipped area

4. when adding guide stars: the guider patrol field.
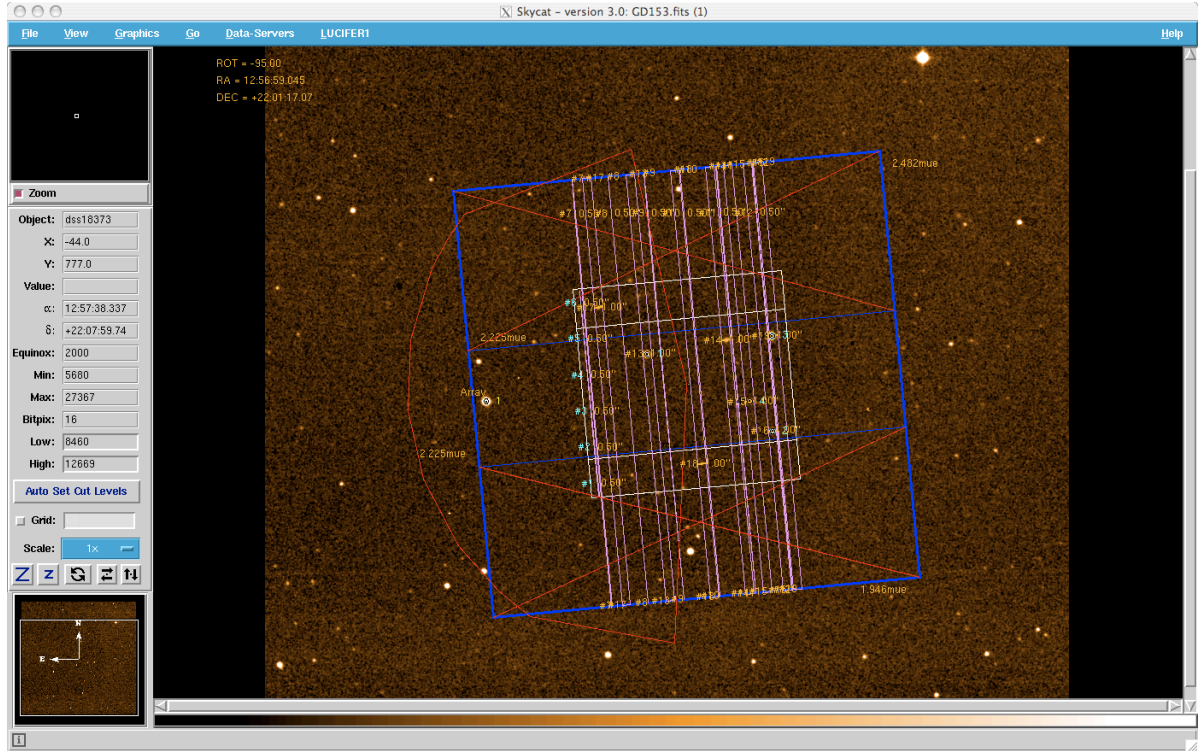
Figure 11: Typical display of the LMS tool.

To make sure that the slits are on the sources when observing, the following rules have to be obeyed:

1. The FITS image must be distortion corrected with high accuracy and the plate scale has to be known with high accuracy, catalog positions must have high astrometric accuracy.

2. Science sources and reference stars have to be taken from the same image or catalog. Their relative positions have to be known to better than 1/6 of the slit width; otherwise slit losses occur.

3. At least two reference stars have to be defined within the LUCIFER field to compensate for pointing and image rotation offsets. Five reference stars are recommended for higher accuracy. The maximum number of reference stars has been set to ten.

4. It is strongly recommended to limit yourself to a maximum of 40 slits per mask.

Slits are generated with the default settings for type, length and width. Changing the default settings will affect newly created slits as well as already existing ones. Slits can be modified and deleted individually by clicking on their number and width labels. When all slits have been positioned, the setup can be saved. During this process, four files are generated:

1. a *.lms file containing the instrument parameters, all slit, reference star, and guide star positions as well as all slit parameters. This file can be loaded again to restore the session,

2. a *.epsf file containing a picture of the mask for direct view (does not show the mask ID),

3. two Gerber files, *.grb, and *_v2.grb cointaining the information for mask cutting. The *.grb file is used for the mask cutting machine available in Munich, the *_v2.grb file can be read by the LBT mask cutting machine.

6.2   Offset and position angle definition

On the LUCIFER images, for a position angle null, North is towards the top of the image, while East is towards the right, unlike the typical orientation of astronomical images. **The position angle** you give **is** however **defined the classical astronomical way = from North to East and given in degrees.**

All offsets are defined in arcseconds.   The telescope can be offsetted either in RA/DEC, the coordinate system is then defined as `RADEC`), or along the lines/columns of the detector, the coordinate system is then `DETXY`. The latter is very useful for e.g. long slit spectroscopy. One also has to define the type of offset:

- cumulative, the offset type is then `relative` and one moves relative to the last position, or

- `absolute`, where all offsets refer to the original position. When offsetting the `RADEC`, one basically tells the telescope where to go; the object on the detector will move in the opposite direction. Offsets in `DETXY` defines where the object will move on the detector.

The active optics duty cycle is typically of 45 seconds, it is therefore recommended to spend at least one minute per position after/before offsetting.
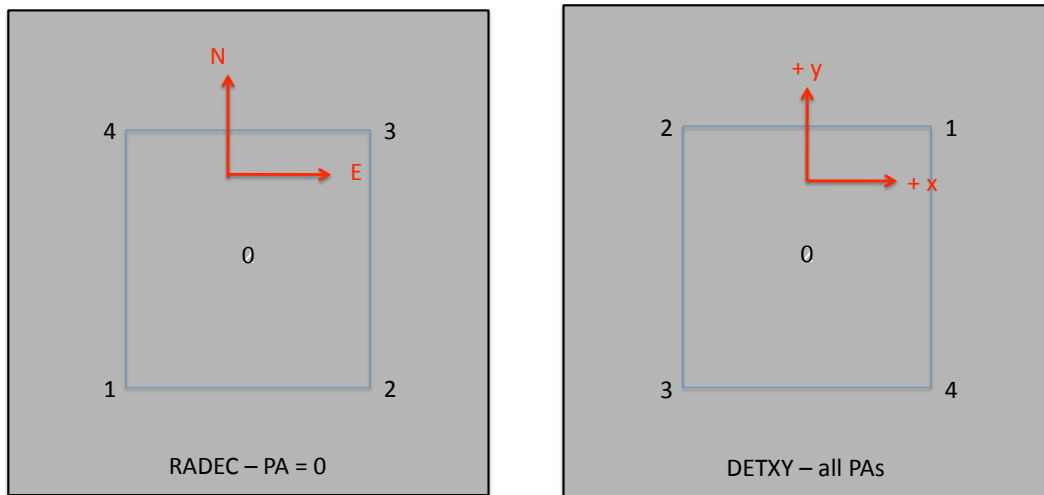
Figure 12: Illustration of the star motion defining a relative offset pattern in RADEC (left) or DETXY (right). For offsets in DETXY coordinates, the position angle does not make any difference, the object will always move the same way on the detector. Offset list: (0,0) - (60,60) - (-120,0) - (0,-120) - (120,0).

6.3   Overhead Calculations

Each read is associated with a given readout time, it is 2 seconds in DCR mode and 10 sec in MER mode. Please note that an integration of 1 minute defined as 2 seconds $\times$ 30 NDIT will have a 50% duty cycle, i.e. it will use 2 minutes of time to complete this 1 minute of on-source integration.

Under good and smooth observing conditions, it has been calculated that offsets in active mode (guiding and sending active optics correction) take in average ~ 18 seconds, while only 4 seconds when performing them in track mode.

Furthermore you have to add the time to create/save the fits file. This time is strongly related to the number of integrations requested and the mode in which data are to be saved. The average time for this process is ~ 12 seconds (between 5 - for single frames - and 20 in practice).

To those times, one has to add the preset time. This time can be only the slewing time, if one uses the track mode. However most observations will be performed in guided mode with active optics correction on. Therefore the guider acquisition and collimation times must be added. Over the Sept.-Oct. 2009 commissioning, over 214 succesful preset (mixed of telescope modes track & active), the average preset time was of 70seconds. The mean time needed for collimation requests (90 measurements) was 135seconds.

A correction of the telescope pointing takes in average 7 minutes.

For spectroscopic observations one has to add the time needed to move the mask in/out of the focal plane. To move a mask from its cabinet storage position to the focal plane, it typical takes 2.5 minutes. Since however it is recommended to move the mask in the '`focal plane`' position while presetting, the overhead quoted here represents only the time to move the mask from the `turnout` position to the focal plane = 45seconds.

Table 10 summarizes all types of overheads.

Example of overhead calculation (based on true examples) - **without** preset or acquisition time:

Imaging
Detector mode: DCR
DIT = 20 sec
NDIT = 3
NEXPO = 1
20 offsets
Total time needed $\quad$ = (20.+ 2.)*3.*20. + 20.* 18. + 20. * 12.
$\qquad\qquad\qquad\qquad$ = 1920 seconds for 1200 seconds of on-source integration
$\qquad\qquad\qquad\qquad$ = 62.5% of shutter open time

Spectroscopy
Detector mode: MER
DIT = 600 sec
NDIT = 1
NEXPO = 1
5 offsets
Total time needed $\quad$ = (600. + 10.) * 5. + 5. * 18. + 5. * 12.
$\qquad\qquad\qquad\qquad$ = 3200 seconds for 3000 seconds of on-source integration
$\qquad\qquad\qquad\qquad$ = 93.7% of shutter open time

6.4   Limiting magnitude & recommended integration times

6.5   Sky emissivity

Sky emissivity is an important parameter setting absolute upper limit for useable DITs in imaging mode. Of course sky emissivity fluctuates a lot in case of clouds and is related to Moon illumination. The bluer a filter, the stronger is the influence of the Moon in the sky background. H band sky emission is pretty independant of the Moon illumination but however strongly affected by variable atmospheric OH lines. Under clear weather and comparable Moon illumination, its value can fluctuate by a factor 2 on short time scale (few tens of minutes). The Mount Graham sky emissivity has been measured at

Table 10: Overview of all overheads times

Action type	Time (sec)
Pointing correction	420
Pure preset	70
Collimation of active optics	135
Offset time	
Track mode	4
Guided mode + active optics on	18
Motion of mask (turnout to FPU)	45
Read out time	
DCR mode	2
MER mode	10
Time to write a file	12

different occasions with LUCIFER, under clear weather conditions, using the N3.75 camera. Table 11 presents some typical results, where the limiting integration time has been rounded.

Filter	No Moon			70% Moon illumination		
	Sky flux (e^-/sec)	DIT_lin (sec)	BLIP (sec)	Sky flux (e^-/sec)	DIT_lin (sec)	BLIP (sec)
z	47	3900	6	120	1400	2.5
J	290	600	< minDIT			
H	1315	140	< minDIT	2400	75	< minDIT
K	3250	50	< minDIT	4300	40	< minDIT
Ks	1640	110	< minDIT			
H2	115	1600	2.5			
Br_gam	125	1400	2.3			
FeII	97	1800	3			
P_beta	42	4300	7			
P_gam	18	10000	16			

Table 11: Measured (N3.75 camera) sky emissivity and corresponding integration time to have the sky background reaching the linearity limit (determined as two third of the full well) and to be background limited.

The background-limited performance (BLIP) is defined as : t_BLIP = $2 \times RN^2$ / Skyflux. It determines the minimum DIT needed to be background limited, defined here for imaging observations in DCR mode (minDIT $\sim$ 2sec) with the N3.75 camera.

6.5.1　Imaging

During clear nights, photometric standard stars have been observed in imaging mode with the N3.75 camera and all available filters. Table 12 presents the derived zero points for all filters.

Please note that the LUCIFER1 z & J broad band filters are wider than the corresponding atmospheric windows (as illustrated in Fig. 13). As a consequence the measured zero points in these bands are quite sensitive to the amount of water vapor in the atmosphere, resulting in flux variations of 3% in z and 6% in J when the atmospheric water vapor doubles.

Table 12: LUCIFER's imaging zero points (defined as 1 ADU/SEC).

Filter	ZP	err(ZP)
Br_gam	21.4	0.02
FeII	21.6	0.03
H2	21.45	0.02
HeI	21.9	0.03
P_beta	21.47	0.03
P_gam	21.43	0.03
Y1	23.5	0.03
Y2	23.46	0.03
OH_1060	21.5	0.03
OH_1190	21.47	0.03
J_low	24.15	0.03
J_high	23.85	0.03
z	24.5	0.03
J	24.85	0.03
H	24.7	0.02
K	24.45	0.03
Ks	24.02	0.03

Table 13 presents some 3 sigma limiting magnitudes derived assuming a seeing of $0.8''$, an airmass of 1.5 and 3mm of water vapor, using a DIT of 10 sec and NDIT=360, to obtain one hour on source integration.

Table 13: Imaging limiting magnitude for a SNR=3 in one hour integration

Filter	Sky mag.	Limiting mag.
z	17.5	24.4
J	16.0	23.9
H	14.0	22.9
Ks	13.0	22.1

6.5.2   Spectroscopy

During clear nights, spectrophotometric standard stars have been observed with the $10''$ wide slit, with the N1.8 camera and all the gratings .

Figure 14 presents typical spectra obtained on spectrophotometric standard stars for all spectroscopic modes. Two stars were used:
FS6: z=13.06, J=13.271, H=13.321, K=13.404 (UKIRT magnitudes)
FS29: z = 12.98, J=13.215, H=13.255, K=13.33 (UKIRT magnitudes)

In z band, one is readout noise dominated, in J band depending on the water vapor in the atmosphere one goes from readout noise dominated to sky background dominated. For H & K, spectra are sky background dominated irrespective of the grating used.

Recommended DITs and NDITs
To avoid unnecessarily long calibrations in the morning, it is recommended to use one of the following
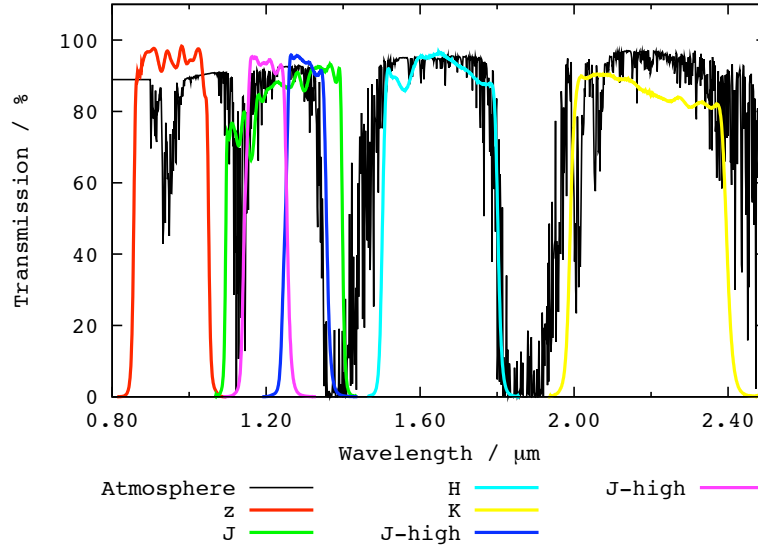
Figure 13: Plot of the LUCIFER broad band filters overlaid on a typical atmospheric spectrum.

Table 14: Typical sky count rate measured between OH lines for the 210_zJHK grating with the 10″ slit and time to be background limited (BLIP) in MER mode with the N1.8 camera.

Filter	Count rate ADU/sec/pix	BLIP sec
z	≤ 0.1	≥ 125
J	≤ 0.2	≥ 62
J	0.5	for 1″ slit - Illustrates the variability
H	0.8	16
K	3	< minDIT
	16	red part of spectrum (thermal background dominated)

DIT/NDIT combination for spectroscopic integrations:

- for bright (4.5 < Vmag < 6) tellurics 2sec*15,

- for fainter standards (6 < Vmag < 10) 30sec*2 or 60sec*1, depending on the wavelength (spectral type and seeing conditions),

- for science observations 120sec*1, 300sec*1, 600sec*1.

For all integrations longer than 60 seconds, it is always (imaging or spectroscopy) recommended to use the MER mode which has a lower readout noise and better cosmetic.

The main limitation for the integration time is given for sky background dominated modes by the sky itself and specifically the OH line intensities. In K band with the 1″ slit, peak counts of up to 12000 have been measured on OH lines. An example is given in Fig. 15, which also illustrates the fact that these lines varies with time but essentially independently of the airmass.
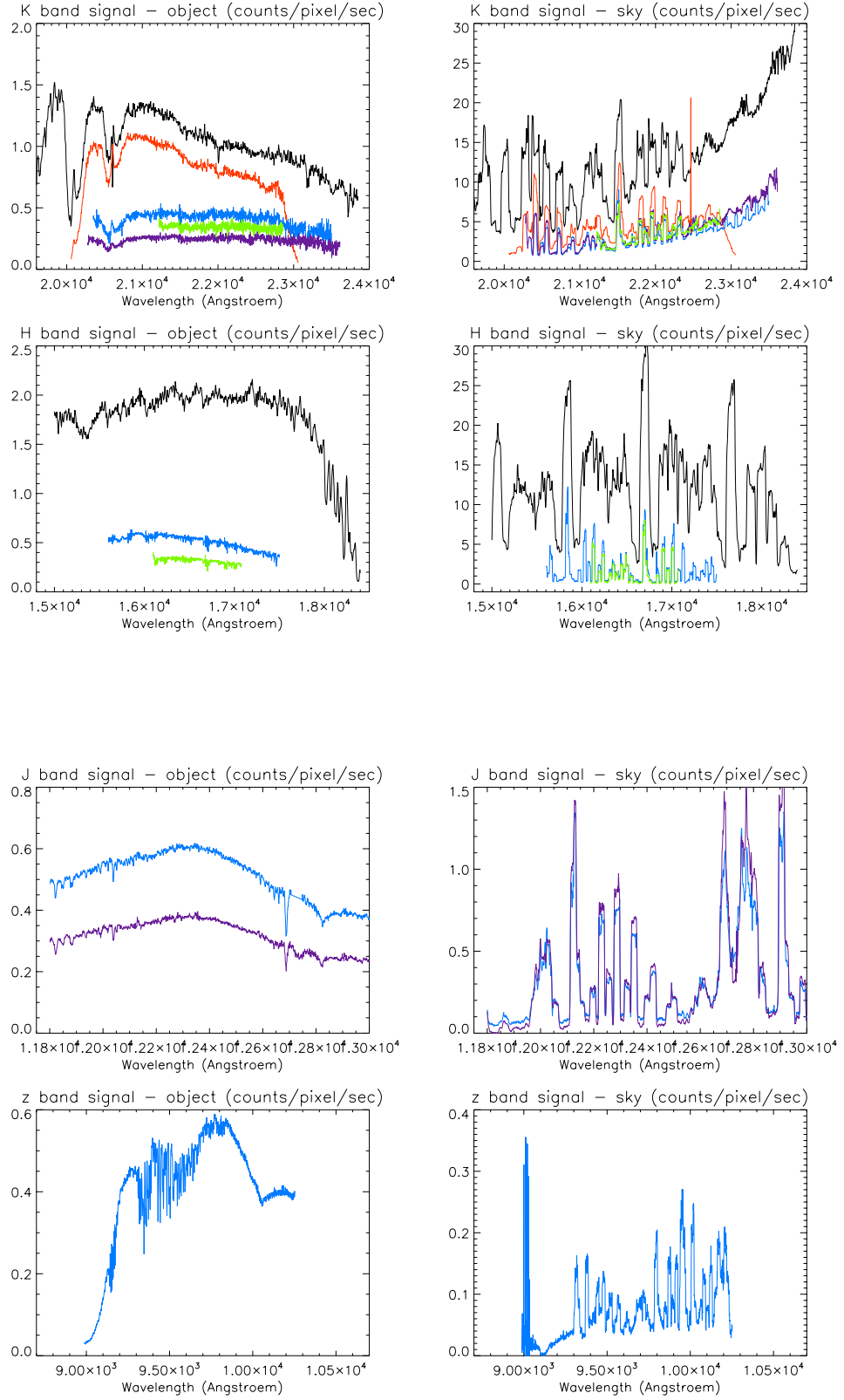
Figure 14: Stellar counts and sky counts in ADU/second/pixel for FS6 and FS29 measured with the 10″ slit and all gratings. Color code: black = FS29 with 200_H+K grating and Order Separator, blue = FS29 with the 210_zJHK grating, red = FS29 with the 150_Ks grating and Ks filter, violet = FS6 with the 210_zJHK grating and green = FS6 with the 210_zJHK grating and the N3.75 camera (unlike all other measurements.
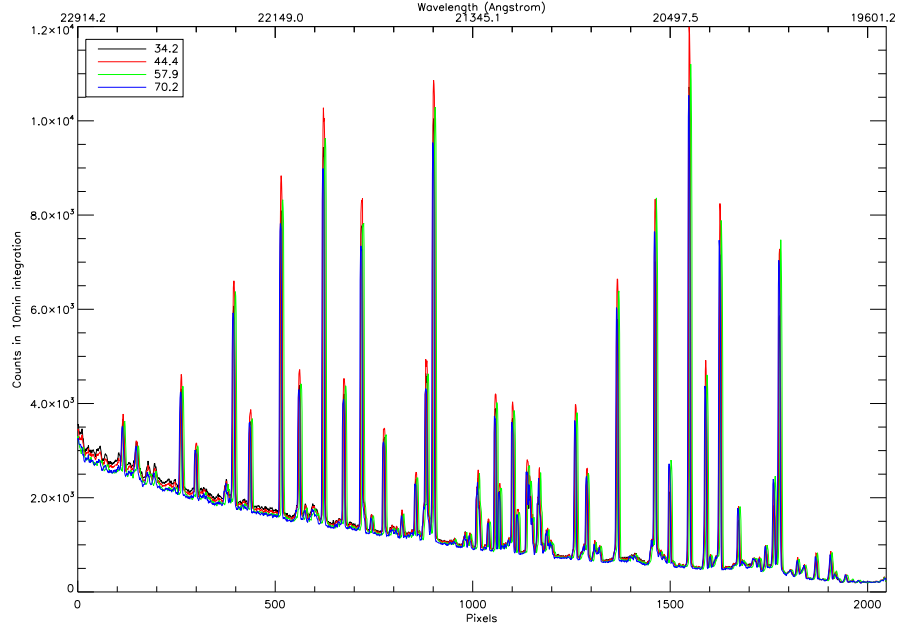
Figure 15: Sky line spectrum measured with the 1″ slit, the 210_zJHK grating and the N1.8 camera at different airmass.

6.6   Calibrations

6.6.1   Sky flats

Sky flats are taken around sunset(/sunrise) with the telescope pointing at zenith, the ventilation doors closed and the observing doors facing away from the sun. The instrument is at nominal rotator angle of 341 degrees and the guide probe parked. You fix your integration time and let the sky luminosity variation do its jobs. Good flats are taken of course only under clear sky conditions. A minimum of 5 frames taken over a range of [3000,17000] ADUs provides a good minimal set of data to derive a flat field.

Because of the relatively small pixel scale of LUCIFER, sky flats in narrow bands have to be started before sunset. Start integrating in K narrow band filters (Br_gam & H2) 35 minutes before sunset. After that FeII can be started, followed by P_gam & P_beta. Once this is finished, you enter the very short time scale period where all broad band filters can be taken, starting with the red filters (K, Ks) and ending with the blue ones (z). When taking morning twilight flats, the order of the filters to be used is of course reversed (short wavelength first, long wavelength (2μm) last).

It is impossible to take all flats in one sunset, you thus have to prioritise your needs. Should no flatfield be available at all, so can you use the internal calibration unit to take imaging flats. Note however that these are representative of true sky flats to within $\pm 10\%$ and thus do not allow for good photometric data reduction.

Table 15 presents the count rate for imaging flatfields with the N3.75 camera. When setting your calibrations' script aim at a level of $\sim$15000 counts (20000 max).

6.6.2   Night calibrations

In principle there is no need to take any night calibration as the flexure compensation is active. To be on the safe side however, for spectroscopy short wavelength calibration and flat field might be useful to be taken overnight. We provide here indication about counts rate per second for these calibrations.

Table 15: Count rates (ADU/s) for internal flat fields with N3.75 camera.

Filter	Halo1	Halo2	Halo3
z	na	na	1450
J	na	na	5500
H	na	na	7100
Ks	na	na	3500
K	na	na	4550
J_low	na	na	2150
J_high	na	na	2150
Y1	na	na	620
Y2	na	na	750
OH_1060	na	2700	110
OH_1190	na	4450	190
HeI	na	2150	180
P_gam	na	3600	150
P_beta	na	6200	na
FeII	na	11000	480
H2	na	8800	350
Br_gam	na	8300	3200

For a quick over night calibration, counts of the order of 200-300 ADUs are enough. Calibrations with longer integration time are recommended to be performed during daytime.

Note: For long slit spectroscopy most wavelengths calibrations can be performed using the atmospheric OH lines present in the spectra (see [Rousselot et al.] for a catalog of these lines). Fig. 16 shows an example of OH lines spectrum obtained with the 210_zJHK grating, the K filter, the 1″ slit and the N1.8 camera.

Flat fields   Knowing the necessary integration time for a given calibration with the N1.8 (/N3.75) camera, multiply (/divide) it by 4 to find the required integration time for the N3.75 (/N1.8) camera for an equivalent signal to noise. Some flatfield images may present a small ripple effect non exisiting in night sky data. This ripple can easily be filtered out in e.g. the Fourier plane.

Table 16 present the count rate for spectroscopic flatfields. When setting your calibrations' script aim at a level of ∼10000 counts (15000 max).

Wavelength calibration

Knowing the necessary integration time for a given calibration with the N1.8 (/N3.75) camera, multiply (/divide) it by 4 to find the required integration time for the N3.75 (/N1.8) camera for an equivalent signal to noise. Table 17 present the count rate for calibration lamp lines as measured with the 210_zJHK grating in all 4 used orders and for different slits. Two values are given: the count rate of the brightest lines. Especially over night, you definitively want to avoid saturating them to avoid remanents effects. The other value represents the average count rate as measured over the typical lines (not the brightest, not the faintest). To increase the signal to noise on these lines without saturating, you increase NDIT, keeping DIT constant.

With the exception of z Band, where Argon and Xenon lamps are recommended to be used at the same time, all other calibrations can perfectly be performed using only the Argon lines.

Do not forget to move manually the calibration unit in and out of the field of view (via the Instrument Manager Panel).
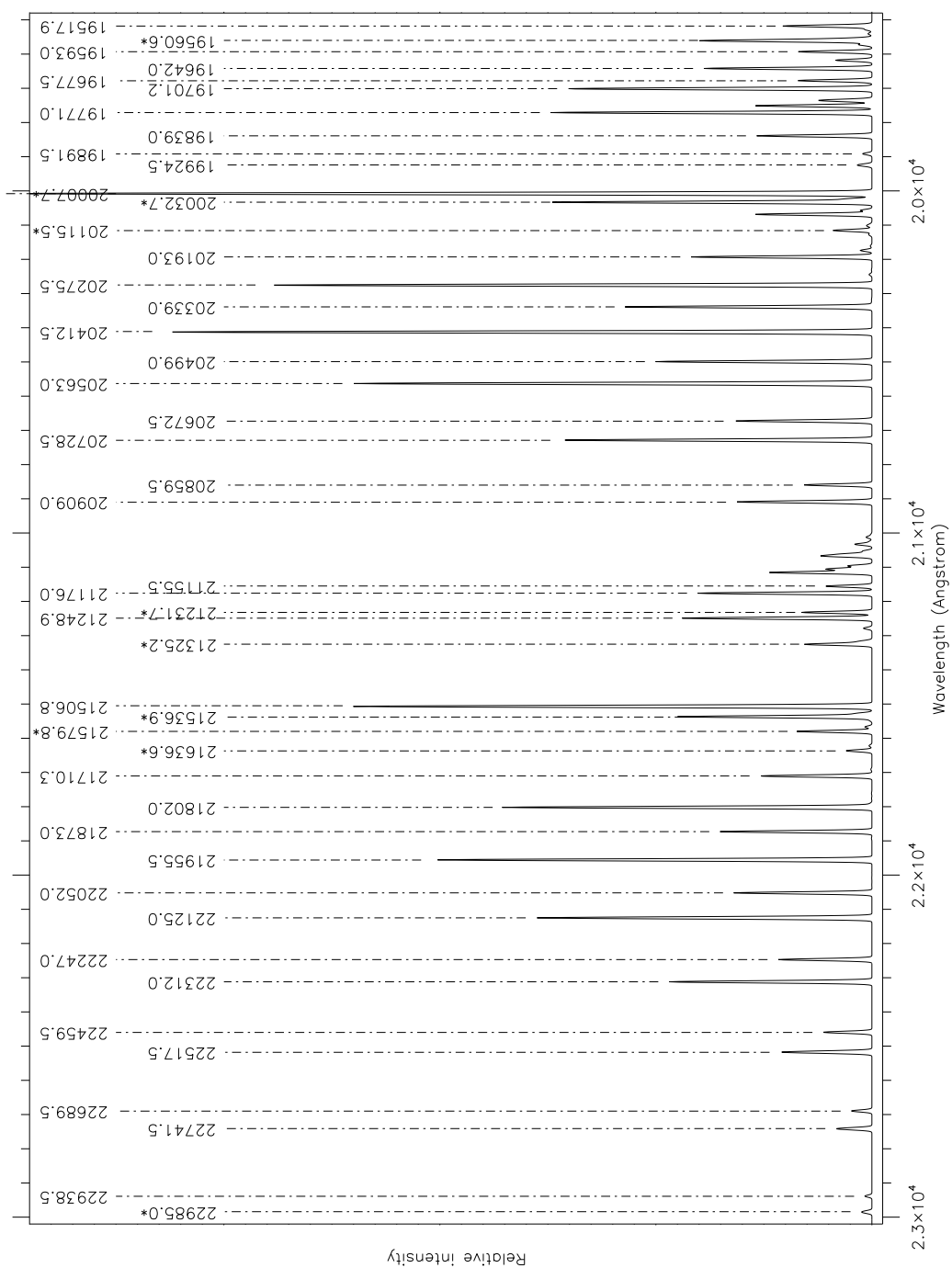
Figure 16: Normalised spectrum of the K band night sky (210_zJHK grating + N1.8 camera), where the OH lines are identified

Table 16: Spectroscopic flat field count rate per second, for different slit width.

210_zJHK grating

Rec. Lamp	halo1 + halo2		halo1 + halo2		halo1		halo1 + halo2	
Slit	z		J		H		K	
	N1.8	N3.75	N1.8	N3.75	N1.8	N3.75	N1.8	N3.75
S150 (0.25″)	(105)	25	(250)	60	(400)	100	(350)	90
S300 (0.50″)	350	90	850	200	1300	350	1100	300
S450 (0.75″)	500	125	1300	350	1900	500	1700	450
S600 (1.00″)	700	180	1700	450	2600	650	2200	550
3-Slit	700	180	1700	450	3100	800	2200	550
(only)		(halo2!)		(halo2!)		(halo2!)		(halo2!)

200_H+K grating

Recommended Lamp	halo2	
Slit	OrderSep	
	N1.8 camera	N3.75 camera
S150	400	100
S300	1300	350
S450	2000	500
S600	2600	700
SpecPhot	2600	700

150_Ks grating

Recommended Lamp	halo2	
Slit	Ks	
	N1.8	N3.75
S150	200	50
S300	550	140
S450	800	200
S600	1100	280
SpecPhot	1100	280

Telluric standard observations for MOS masks
   - Move the MOS mask to the turnout position during the preset to the telluric star.
- Center the star to pixel (1024,1024).
- Let the acquisition finish with a blind offset that centers the star within one of the desired slitlets.
- Run the "science" script to offset the telluric star from one slitlet to another.
- (Select slitlets at the "right" and the "left" sides of the mask to cover the entire spectral range)

How to calculate the needed offsets
   Use the information in the lms file associated with your mask.

From the lms example below, using the formulae below, one can calculate the separation between the center of field, defined at position (1024,1024) for the mask creation and the first slit where on wishes to put the telluric standard.

$$\Delta x = \Delta \alpha \times cos(ROT) - \Delta \delta \times sin(ROT) \qquad (1)$$

$$\Delta y = \Delta\alpha \times sin(ROT) + \Delta\delta \times cos(ROT) \tag{2}$$

Distance between center of slit #12 and "pointing center" = $\Delta\alpha$ = 70.311", $\Delta\delta$= 8.469". These values have to be entered in the acquisition script as blind offset (DETXY relative). Once the script is finished, it is still time to re-check the centering within slitlet #12.

In the science script itself, one then introduces the offset (DETXY relative) to move the object from slitlet #12 to slitlet #13 = $\Delta\alpha$ = -120.265", $\Delta\delta$= -5.435"

Slit	N1.80 camera		N3.75 camera	
	Integration time (sec)	counts (B./T. line)	Integration time (sec)	counts (B./T. line)
210_zJHK grating				
z Band - Recommended lamps: Ar+Xe				
S150	(2+2	3000/1500)	2+2	750/400
S300	2+2	4000/2000	2+2	1000/500
S450+S600	2+2	12000/6000	2+2	3000/1500
SpecPhot	2+2	15000/7500	2+2	3500/1800
J Band - Recommended lamps: Ar (+Ne)				
S150	(10+10	1500/300)	30+30	1200/250
S300	10+10	2000/400	30+30	1500/300
S450+S600	10+10	6000/1200	10+10	1500/300
SpecPhot	10+10	7000/1400	10+10	1700/350
H Band - Recommended lamps: Ar+Xe				
S150	(30+30	4000/200)	120+120	4000/200
S300	30+30	5000/250	120+120	5000/250
S450+S600	30+30	15000/750	30+30	3500/200
SpecPhot	30+30	17000/800	30+30	4000/200
K Band - Recommended lamps: Ar+Ne+Xe				
S150	(30+30+30	500/200)	120+120+120	500/200
S300	30+30+30	600/250	120+120+120	600/250
S450+S600	30+30+30	1800/700	60+60+60	900/350
SpecPhot	30+30+30	2000/800	60+60+60	1000/400
200_H+K grating				
OrderSep - Recommended lamps: Ar+Xe				
S150	10+10	2000/300	20+20	1000/150
S300	10+10	3000/400	20+20	1500/200
S450+S600	10+10	9000/1200	20+20	4500/600
SpecPhot	10+10	10000/1300	20+20	5000/700
150_Ks grating				
Ks Filter - Recommended lamps: Ar+Xe+Ne				
S150	10+10+10	800/150	30+30+30	600/100
S300	10+10+10	1000/200	30+30+30	750/150
S450+S600	10+10+10	3000/600	30+30+30	2300/600
SpecPhot	10+10+10	4000/700	30+30+30	2500/650

Table 17: Arc lines count rate per second. The integration time are for each lamp separately, but they of course can be switched together. The counts are given for the brightest (B.) lines and the average of the other "typical" (fainter) lines (T.).

	lms input information		Comments

```
# created by SKYCAT-TOOL -- LMS-plugin V1.13
# INS.MASK.ID : 910509
# ------------------------------------------
```

	TEL.TARG.ALPHA	022539.027	*Pointing information*
	TEL.TARG.DELTA	+620530.480	*Position at (1024,1024)*
	TEL.ROT.OFFANGLE	-30.000	
	TEL.TARG.EQUINOX	2000.0	
	TEL.TARG.TYPE	COORDINATE	
	INS.SLIT.NUMBER	25	*Number of slits in the mask*
	INS.TARG103.NAME	refslit	*Information about ref. slit #3*
	INS.SLIT3.REF	103	*used for MOS alignment*
	INS.TARG103.SHAPE	STRAIGHT	
	INS.TARG103.WID	0.5	
	INS.TARG103.LEN	0.5	
	INS.TARG103.ROT	0.0	
	INS.TARG103.WIDMM	0.300	
	INS.TARG103.LENMM	0.300	
	INS.TARG103.XMM	-13.000	
	INS.TARG103.YMM	-70.000	
	INS.TARG112.NAME	NN	*Information about a "science" slit*
	INS.TARG112.SHAPE	STRAIGHT	*selected because on the right side of field*
	INS.TARG112.WID	1.0	
	INS.TARG112.LEN	4.0	
Extracts of a lms file:	INS.TARG112.ROT	0.0	
	INS.TARG112.ALPHA	022547.099	
	INS.TARG112.DELTA	+620612.970	
	INS.TARG112.WIDMM	0.600	
	INS.TARG112.LENMM	2.400	
	INS.TARG112.XMM	-42.184	
	INS.TARG112.YMM	-5.106	
	INS.TARG113.NAME	NN	*"science" slit*
	INS.TARG113.SHAPE	STRAIGHT	*selected because on the left side of field*
	INS.TARG113.WID	1.0	
	INS.TARG113.LEN	4.0	
	INS.TARG113.ROT	0.0	
	INS.TARG113.ALPHA	022532.650	
	INS.TARG113.DELTA	+620508.130	
	INS.TARG113.WIDMM	0.600	
	INS.TARG113.LENMM	2.400	
	INS.TARG113.XMM	29.968	
	INS.TARG113.YMM	-1.814	
	INS.TARG30.ALPHA	022535.734	*Information about first reference star*
	INS.TARG30.DELTA	+620540.850	*#1 in MOS acquisition*
	INS.TARG39.ALPHA	022540.637	*Information about last reference star*
	INS.TARG39.DELTA	+620419.340	*#10 in MOS acquisition*
	INS.TARG40.ALPHA	022517.549	*Information about the guide star selected*
	INS.TARG40.DELTA	+620757.250	
	INS.RSTAR.NUMBER	10	*Number of reference stars selected*

6.6.3   Calibration Plan

The calibration plan on a long term is the responsability of the LUCIFER LBTO instrument scientist. We however shortly highlight our recommendations.

Topic	Frequency	Comment
Flat fields	upon observer's request	to be taken on sky
Photometric standards	upon observer's request	clear conditions
Telluric standards	for each spectro. observation	within 2 hours of the observation and a maximum airmass difference of 0.2
Spectrophotometric standards	upon observer's request	same as above
Spectroscopic arcs & flat fields	for each spectro. observation	to be taken the morning after the observations
Darks	daily	for the readout modes used

Note: Darks with exposure time (DIT×NDIT) less than 1 minute can be taken with the dome dark and the two blind filters. For higher exposure time darks, the blind mask has to be put in the focal plane. This has the advantage to allow dome lights to be turned on.

The only internal calibration, which absolutely needs to be taken with no light in the dome is the spectroscopic flatfield, for which the calibration unit is needed. Although arcs could be taken with the dome lights on, it is not recommended.
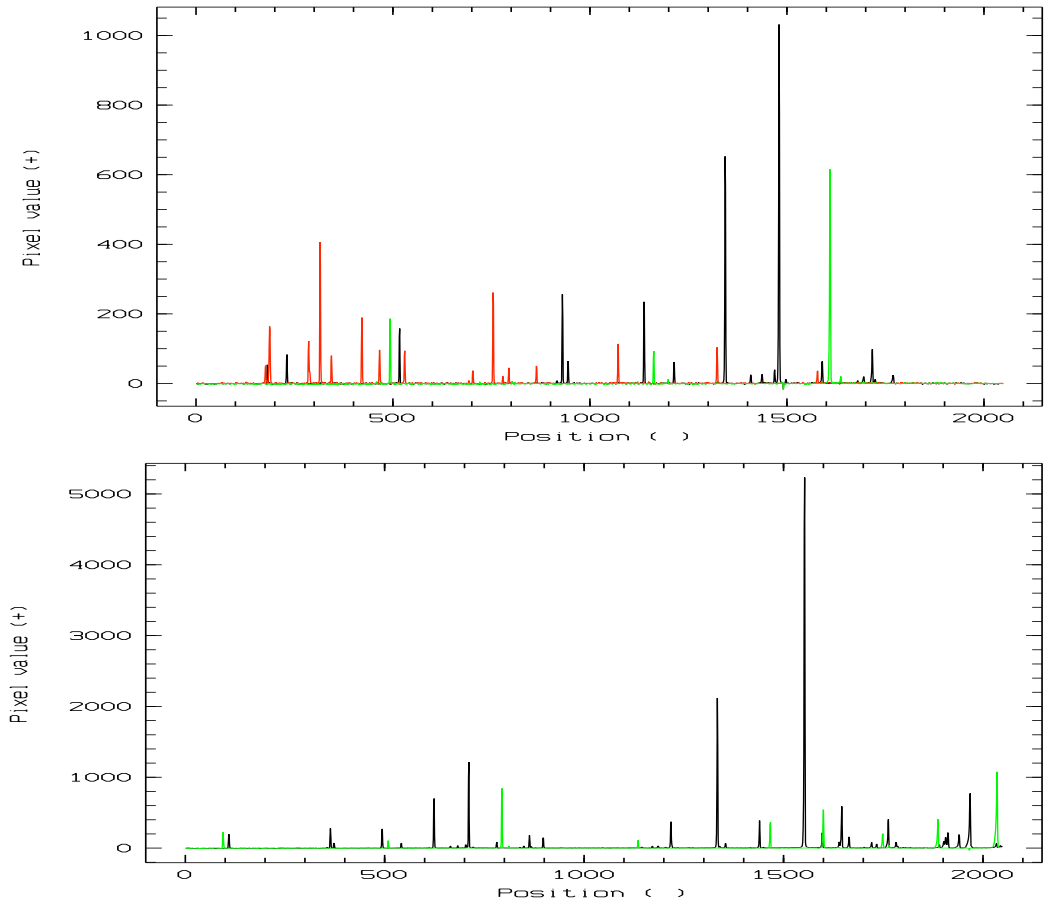
Figure 17: Calibration lines measured with the LS300 (0.5″) slit for the 150_Ks (top) and 200_H+K (bottom) grating. Ar is represented in black, Xe green and Ne red (when available). From top t bottom: z Band, J band, H band & K band.
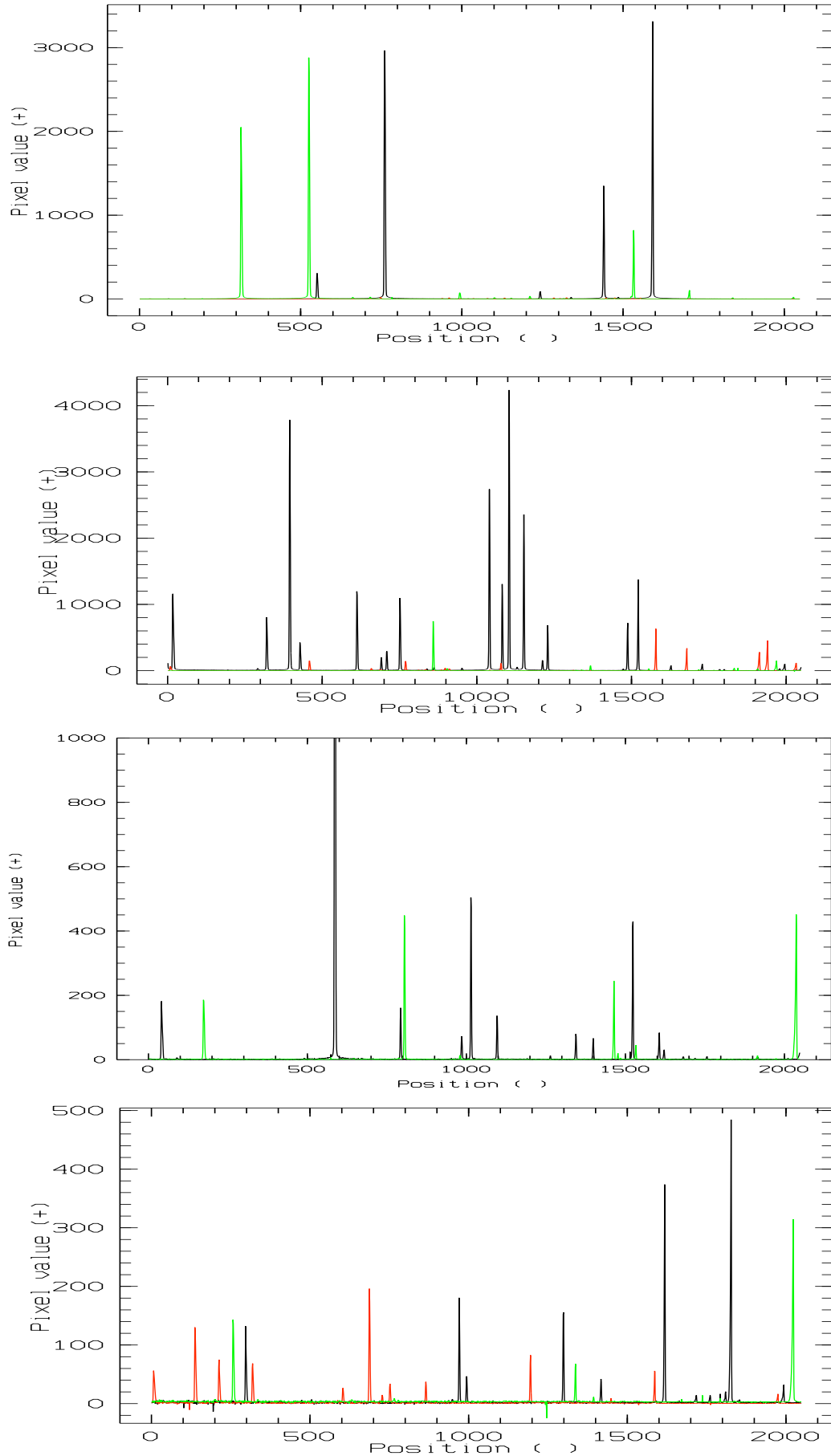
Figure 18: Calibration lines measured with the LS150 (0.25″) slit for the 210_zJHK grating. Ar is represented in black, Xe green and Ne red (when available). From top t bottom: z Band, J band, H band & K band.

7 Observing with LUCIFER

The normal observing operation with LUCIFER is entirely performed through scripts (Sect. 7.4). The interactive observing mode (Sect. 7.3) is described in detail here since it allows to introduce the definition of all parameters needed for scripts.

7.1 Login and Software Start

Usually, the Lucifer control software (LCSP) is running continuously on the SUN V880 workstation. That means the observer has only to start the necessary GUIs. Therefore he/she has to use the dedicated LBTO linux machine and open a NXClient connection with the following parameters:

- User name: observer

- Password: `provided at the LBT`

- host: sun-luci

After being connected to the SUN X environment, double click on the *Start_LUCIFER* icon on the desktop. This will open all the necessary GUIs for the observations.

The readout software initial panel requests you to press on OK. With the exception of the observer name that you can specify there, to see it updated in the FITs header, do not change any other of the settings. Also Do NOT close any of the terminal window that opens automatically.

7.2 Start and end of night procedures

7.2.1 Start of night

- Set a new directory (path file) in the Readout Manager GUI (Fig. 22)

- Set a new filename (change the date) in the Readout Manager GUI (Fig. 22)

- Save a dummy image to stop the archive complaining it has nothing to archive

- If the sky is clear, go on with taking twilight sky flats (at zenith before sunset); see section 6.6.1

- Then move on with the pointing correction procedure; see paragraph 5.2

7.2.2 End of the night

- Put the two blind filters and the N1.8 camera in position and set the detector to DCR mode with DIT=2sec (manual saving) while the operator is closing the telescope

- Start the flush_detector.txt script

- Prepare your scripts to take the dark calibrations

- Once the dome is closed and dark (no light), the telescope at zenith, rotator angle = 341 and the guide probe has been parked, you can take the needed calibrations with the calibration unit

- When done with the calibration unit, set again the two blind filters and run the flush_detector.txt script again

- Put the BLIND mask in FPU and start your dark calibration script

7.3   Interactive Observing

The instrument can be fully controlled by three GUIs: the instrument- (Fig. 19), telescope- (Fig. 21) and readout-GUI (Fig. 22). They all use the same kind of process: by pressing the commit button after selecting the desired setup, the software collects all properties from the GUI and builds up a setup which will be send to the appropriate software service and from there to the hardware. The current setup is highlighted in green, while the configuration selected to be set next appears in yellow. This allows the user to track the changes of the instrument set-up. When a set-up is being performed, the full panel turns yellow.

Note: Should accidently a wrong filter, camera or grating have been selected, press the current green button to discard your previous selection.

Figure 19: The LUCIFER instrument control GUI allows classical access to all relevant components of the instrument.

7.3.1   The Instrument Control GUI

This GUI gives the user access to all instrument relevant parameters of LUCIFER. It consists of several sub panels which are explained here in more detail.

MOS Panel   The use of masks in the focal plane is controlled from the left part of the GUI (see fig. 19). The current state of the unit is shown in the text fields MOS STATE and MASK IN USE. During the movement process a moving bar is visible.

Note: In the case that the MOS STATE changes to UNKNOWN (which will be color coded in red) the instrument scientist has to be contacted immediately. **STOP doing anything with LUCIFER when this has happened!!**

The MOS state can be changed by using the two drop down menu, one for the mask state (`Mask To Position`) and the one with the mask number to use (`Mask To Use`). The latter one shows the names and numbers of the current masks in the cabinet. It is updated after each cabinet exchange by the responsible technician or the instrument scientist in charge. Three "mask states" can be selected from the pull down menu:

1. NO MASK IN USE = all masks are in storage position. This is the default configuration (used for imaging)

2. MASK TO FPU = moves the mask that has been selected from the drop down menu `Mask to Use` into the focal plan. This is the default set-up for spectroscopic observations.

3. MASK TO TURNOUT = moves the mask out of the focal plane but not back to the storage position to save time. This is needed for spectroscopic acquisition (section 7.5.2).

Calibration Panel   The next panel in this GUI lets the user control the calibration unit. It can be moved in and out from here and the current lamp status is shown. To switch on the lamps an extra GUI (Fig. 20) can be accessed via the OPEN GUI button. There all lamps can be selected at once.

Note: When asking to move the calibration unit in, it sometimes happens that on the first click on "IN" following illegal error appears: Problems with Calibration Unit device (WebIO): java.lang.IllegalMonitorStateException Do not worry. Just try again. Should the problem persists so ask your LBTO support astronomer to move the calibration unit in position from the corresponding engineering panel, to which you do not have access as user.

Table 18: Definition of the lamps in the calibration unit.

| Position | Name of the lamps in the Telescope Control GUI | | | | | |
	#1	#2	#3	#4	#5	#6
	Name of the lamps in the Calibration Unit GUI					
Name	Ne	Ar	Xe	halo1	halo2	halo3
Comment	Arc lamps for wavelength calibration			Halogen lamps for flat fields		
				The lamp intensity decreases from #1 to #3		

Flexure Compensation panel   In the flexure compensation panel the current flexure mode of the instrument is shown and can be changed via the ON/OFF drop down menu. When flexure compensation is turned ON using the GUI, it is not switched off by running scripts, even if they have the flexure compensation flag set to OFF. Conversely, when the flexure compensation is turned OFF using the GUI, scripts can actively switch the flexure compensation on or off (depending on the status of the flag). Note that at the end of script the flexure compensation is then switched off.

Camera Panel   The camera wheel panel allows the camera selection. The N3.75 camera is for imaging and the N1.8 meant for spectroscopy.

Note: the N30 camera has been designed for observations together with adaptive optics and is currently not installed.
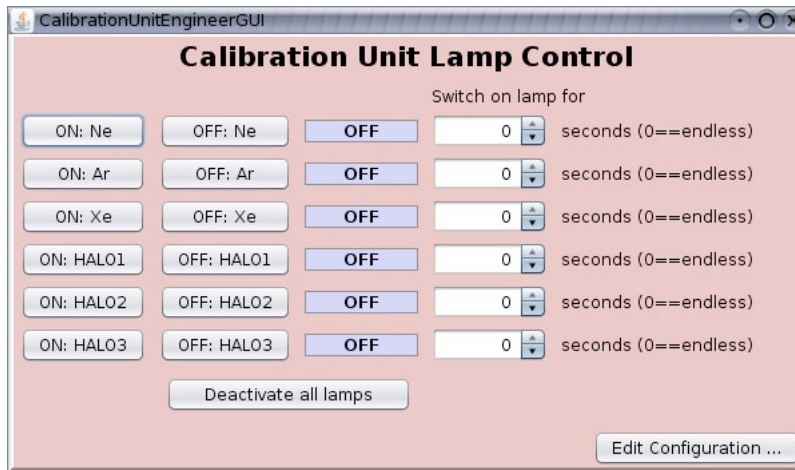
Figure 20: The LUCIFER Calibration Unit GUI.

Note: If moving from one camera to the other, you notice the field is not centered again, it is most probably because the camera wheel did not reach its position properly. In this case simply move to another camera and then back. If needed, ask your LBTO support astronomer to re-initialise the camera wheel, from the corresponding engineering panel, to which you do not have access as user.

Grating Panel From the grating unit panel the mirror position (for imaging) and three different gratings can be chosen. Furthermore the current wavelength is shown and the text field *Desired Wavelength* allows user input for new wavelength. The unit is in microns and the maximum meaningful precision is 0.1nm. The desired grating has to be specified before the wavelength is typed in, since the wavelength value is cleared when a new grating unit position is selected. After typing in a new wavelength the user has to click the SET WAVELENGTH button and of course the COMMIT button to execute the setup change. When no wavelength i given, the selected grating is moved into position but it will not be tilted to a defined angle. Use this option only when the desired grating is fixed, machenically, to a nominal angle; as is currently the case for the 150_Ks grating.

Pupil Viewer Panel This is mostly needed for optical calibrational work and not necessary for the normal observing mode.

Filter Wheels Here the user can choose the filters to observe with. When both filter wheels need to be moved, filter wheel #1 is moved first before filter wheel #2 is moved. Keep this in mind when making a manual set_up to avoid going through 2 open (clear) positions.

Note: All combinations are possible but some might not meaningful, so please be alert.

Commit The COMMIT button is located on the upper right side of the GUI. Here the new setup can be executed. As long as a component inside LUCIFER is still moving from a former setup, the COMMIT button is blocked. The INITIALIZE button is located left from the COMMIT button . After a software restart this button has to be pressed to re-initialise all instrument functions. During normal operations there is not need to use this button.

Alarm Status Panel Here the overall status of the environmental systems of LUCIFER is indicated. A change in temperature or pressure will be indicated by a warning or an alarm, which is color coded red. The latter one is very critical and requires an urgent system check by an instrument (engineer) expert.

7.3.2 The Telescope Control GUI

This GUI uses a direct service connection to the Telescope Control Server (TCS) interface. An error when starting the *Telescope Service* might be caused by a non running interface on the TCS side. Please inform the LBTO instrument scientist for support. The GUI (Fig. 21) follows the same philosophy as the Instrument Control GUI, the COMMIT button sends the new setup to the telescope service.
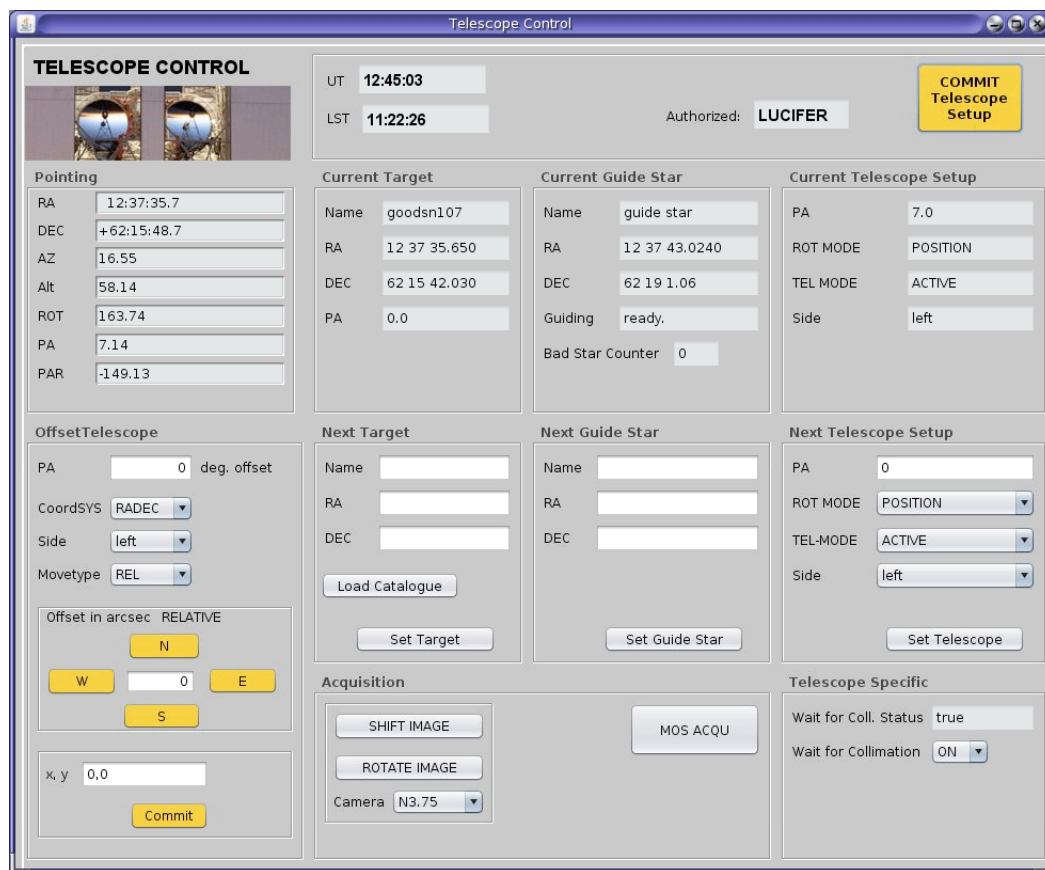
Figure 21: The LUCIFER Telescope Control GUI provides all features to set up the telescope.

Pointing   On the left side of the GUI the current position of the telescope is shown, including the rotator, position and parallactic angle. It is updated regularly so the user is able to follow the telescope motion.

Note: When these text fields are empty, it indicates that a connection to the TCS is not working properly or a subsystem is not running on the TCS side. This can be checked by the Telescope Operator.

Offset Telescope   This panel is necessary for the acquisition process. The user can choose a position angle (PA) offset and telescope position offsets. There are three pull down menues available:

- **CoordSys**
  Lets the user choose the valid coordinate system.
  1. RADEC Offsets are interpreted as sky coordinate offsets.
  2. DETXY Offsets are interpreted as detector coordinate offsets. This option is useful for the acquisition procedures.

- **Side**
  This describes which mirror is in use: Left (LUCIFER1), Right (LUCIFER 2) (not available yet)

- **Movetype**
  Describes the type of offset: relative or absolute.

Underneath these pull down menues buttons in a star pattern for 4 sky orientations are located, allowing an offset in these direction. The offset value in *arcsec* has to be typed into the appropriate text field in the middle of the pattern. Pressing one of the orange orientation buttons will directly lead to a movement of the telescope. Furthermore x and y offsets in *arcsec* can be typed into the bottom text field, divided by a comma to move the telescope directly in two directions. The small COMMIT button will also directly lead to a movement of the telescope.

Current Setup Information   There are three sub panels describing the current values of the target, guide star and telescope. The current target and guide star information is stored locally since the telescope does not provide this. This means that after a new start of the LUCIFER control software no information will be present.

Setting Up The Telescope   To set a new target the user can use the text fields for target and guide star or a ASCII list which can be loaded via the LOAD CATALOGUE button in the *Next Target* sub panel.

The Input syntax for RA and DEC has to be in sexagesimal format like
RA **06 09 07.836** and DEC **24 22 32.35** for example. The coordinates have to be in **J2000**.

The ASCII catalogue for target and guide stars has to be formatted as follows using a *pipe* (|) as the delimiter.

```
TARGETNAME|RA|DEC|GUIDE* NAME|GUIDE* RA|GUIDE* DEC|PA|RA_PPM|DEC_PPM
```

For example:

```
FS29    |21 52 25.3835|+02 23 19.556|GS_r14.3_d3.77_pos047.362|21 52 36.538|+02 25 52.21|45|23.00|-302.98
```

For each target an appropriate guide star **has to be** defined by the observer. As the telecope SW does NOT provide automatic guide star selection, the user has to select the guide star(s) in advance. It is possible to open several catalogues at a time. By clicking on the desired line in the catalogue and using from the menu COMMIT->COMMIT STAR sends the selection to the telescope GUI but not the telescope yet.

After the next target and guide star have been set, additional telescope specific parameters can be changed. The typical oberving setup is POSITION ACTIVE.

- **ROT MODE**
  Here the rotator mode can be set.

  1. POSITION
  2. PARALLACTIC

- **TEL-MODE**
  Here the telescope mode can be set to

1. STATIC

2. TRACK
   Only telescope tracking is running.

3. GUIDE
   Tracking and guiding is running without active optics.

4. ACTIVE

5. ADAPTIVE The full package for normal observing: Tracking+guiding+active optics

The position angle is defined with respect to North when ROTMODE is 'position'. When ROTMODE is 'parallactic', the angle is defined with respect to the parallactic angle. Thus, a parallactic mode preset with an angle of 90 will orient the slit parallel to the horizon.

All three input sub panels (*Next Target, Next Guide Star, Next Telescope Setup*) have to be activated by clicking the corresponding SET TARGET, SET GUIDE STAR, SET TELESCOPE button. When the input is okay the button will change to green. After all three are green the COMMIT TELESCOPE SETUP button can be pressed.

The bottom right part of the panel allows you to set the "wait for collimation flag". This has to always be on then scripts will start integrations after the collimation is successful; otherwise integrations may start just after guiding started and independantly of the telescope delivered image quality. Should a preset be successful but the active optics not starting or not collimating, change this flag to "OFF" so the telescope preset "finishes". Then you can preset again (do not forget to reset the flag to "ON" again).

7.3.3   The Detector Read Out GUI

Figure 22: The LUCIFER Read Out Manager GUI. All necessary detector parameters can be set from this GUI.

The third control GUI for interactive observations with LUCIFER is the Readout Control GUI (Fig. 22). The left region of the GUI shows the current detector set-up values like e.g. the readout mode in use, the integration time, the last and next file names of the images, etc. The countdown clock located in the upper left corner indicates whether an integration is currently on-going. A static time value on a black background (as shown in the figure) indicates that the detector is currently idle. When a readout is started the clock changes to a yellow background and the remaining integration time (for one exposure) starts to count down.
The right part of the GUI allows to set new readout (DIT, NDIT, NEXPO) values and to start/stop exposures. The "Start Read" button starts an integration with the current settings displayed in the left part. The "Abort" button can be used to stop the on-going integration.

Note: no confirmation window will be displayed before the integration is stopped!

To determine that images should be saved manually or automatically the pull-down menu next to the "Save image" button is used. The color of this button also indicates whether the last image has already been saved (the button is green) or not (the button is orange).

Note: Changing the selected save mode value from "manual" to "automatic" would save data if that action takes place before an integration or a read, but does *not* save the last frame already read automatically.

The "Frame type" pull down menu determines the value of the OBJECT and DATATYPE keywords that will be written into the FITS header of the image. When the datatype is "SCIENCE", the OBJECT keyword value for the fitsheader will be read from the telescope service at the beginning of the integration. For any other selection the OBJECT keyword in the fitsheader will be set to "undefined".
The lower right area of the GUI allows to set the values for a new readout set-up. The two available readout modes can be selected with the "ROEMode" pull down menu. There are three different options to save files ("Savemode" pull down menu):

1. **normal:** for each exposure, the detector is read out NDIT times for DIT seconds. When the images are saved, NDIT files are written, each with DIT seconds exposure time. This is repeated for the number of frames required.

2. **integrated:** only one frame is saved. It corresponds to the sum of the DIT×NDIT seconds of integration.

3. **cube:** data are saved in a cube with NDIT planes.

"Filename root" allows to set the root of filenames that should be written. If the last character of this string is not a digit, the GEIRS read out software will append four digits to this root automatically and write files with ascending numbers. A proven practice is to end the root of the file names with an underscore "_" character. Typically frames are called "luci_YYYYMMDD_". The "Save Path" text field can be used to determine a new saving directory. This can be done by typing the new path directly into the text field or by using a file chooser which is opened when the "..." button is pressed. If the new save directory does not exist, a message window appears after clicking the "Set new values" button, to ask you to create this new directory.

Sending the new setup to the readout manager is done by clicking the "Set new values" button located directly below new readout setup area. If this button is orange, changes in the readout setup have not yet been sent since the last time the button was pressed. Like the "Save image" button this button changes to "green" when the changes have been sent successfully. At this point the information on the right and left side of the panel should be identical. To be able to sent a new readout setup, all values have to be set to sensible (i.e., non negative) values. The "Filename root" and "Save Path" fields can be left blank, however. In this case, the current values will be left unchanged.

After a read the newly observed image is displayed on the LUCIFER display (Fig 23). This display does not offer as many options as a typical SkyCat. but allows to have a quick check at the data taken

(sky/object counts & centering). On the top right part of the panel few statistics vaues, calculated over the small window represented above it, are provided. For a quick look image analysis as well as for the acquisition procedure, the image has to be saved. This triggers an automatic uploading of the frame in the SkyCat display on same desktop.
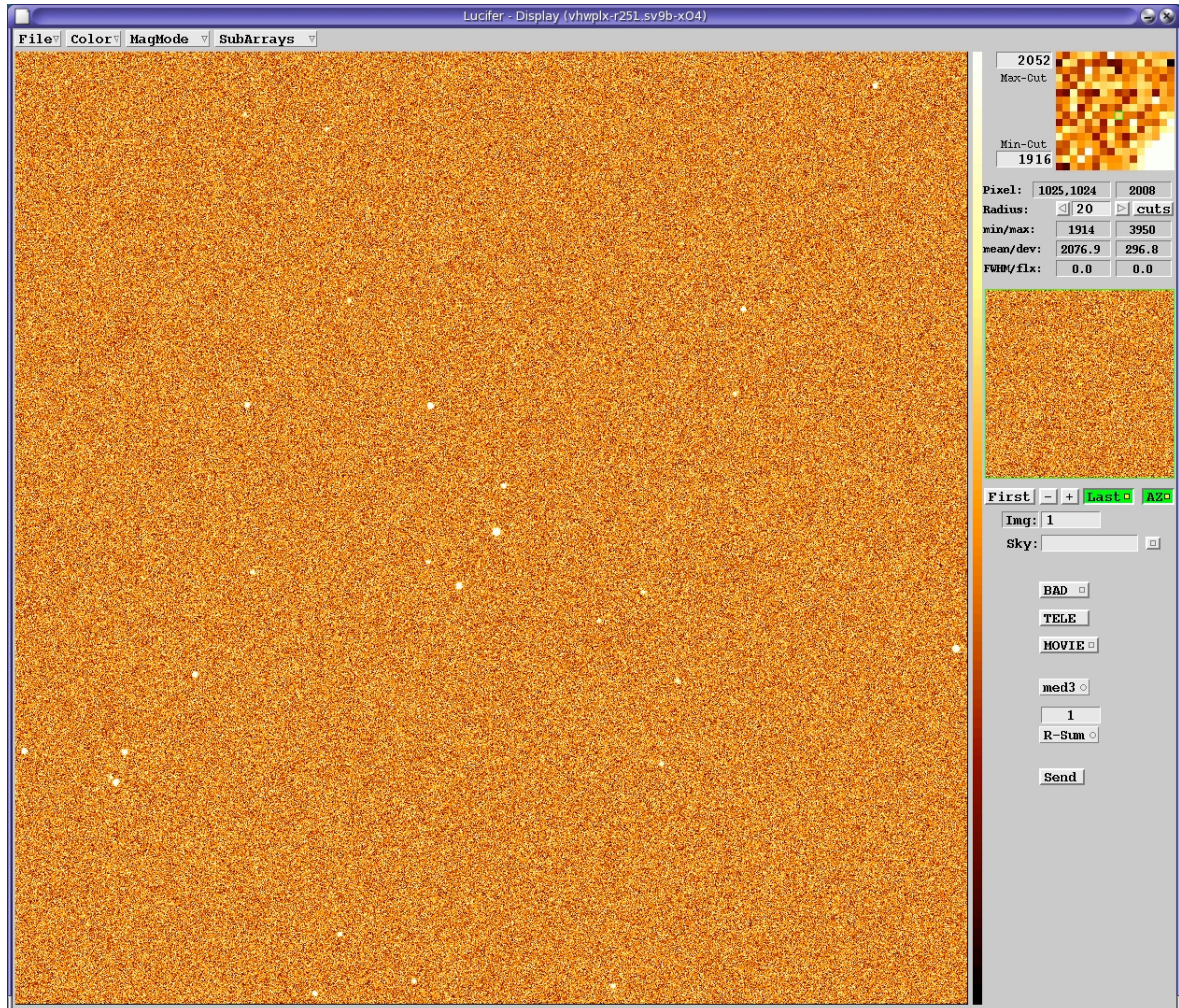
Figure 23: The LUCIFER image display.

Archiving information

It is possible to write archiving information to the FITS header of the LUCIFER files. Three different archiving keywords are written:

PARTNER = 'NOPARTNER'/ name of partner(s)
PI_NAME = 'NOTSPECIFIED'/ name of the PI(s)
PROP_ID = 'NOTSPECIFIED'/ proposal ID

In this example the default values that will be used if no other information is available are shown. Archiving information can be set using the ReadoutManager GUI or via scripts.

The current archiving information is displayed above the readout setup information, in the "Archive Info" box (Fig. 22).To change the current archiving information use the Set archive info... button. This opens the dialog window presented in Fig. 24.

The three different entries can be edited as necessary. The `PI Name` and the `Proposal ID` entries can be chosen freely, for the `Partner` information some rules are applied:

Figure 24: The archive information editing window.

1. **Only the following partner names are valid:**
AZ,COMMISSIONING,INAF,LBTB,LBTO,LBTSDT,OSURC
2. Multiple valid partner names can be specified, if more than one name is used, the names must be separated by a comma (,). No comma is allowed after the last partner name. Spaces ( ) are allowed before or after the partner name but will be removed in the FITS header entry.
3. If no partner name is given (i.e., the text field is empty) the default name `NOPARTNER` is used.
4. If an invalid partner name is given, an error message is displayed and the preceding partner information is restored.

After entering the new values by clicking Ok, the new information is displayed in the ReadoutManager GUI (Fig. 25) and used for all files that are saved from now on, using the GUI.
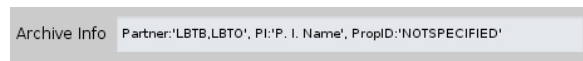
Figure 25: Extract of the LUCIFER Read Out Manager GUI showing the updated archive information.

7.4   Script Observing

Usually, observations with LUCIFER will be performed by means of ASCII scripts. These scripts allow the setting of all relevant instrument parameters as well as the control of the telescope. Scripts are very convenient and help significantely to maximize observing efficiency.

The scripts are structured to clearly outline which part of the set-up corresponds to the different sub-system telescope, instrument, detector and parameters specifics for the archive system. For example all parameters relevant for the instrument set-up have to be set within the [*_INSTRUMENT_SETUP] section. Any parameters not needed to be set can be commented out with a "#" at the beginning of the line. Should you wish to use a pre-prepared script which contains a telescope set-up but actually do not need it, so can you comment the entire setion out by adding the "#" symbol before the [START_TELESCOPE_SETUP] and [END_TELESCOPE_SETUP].

Note: Altough the save path and filenames for the images can be specified within the scripts, it is often more convenient to leave these two parameters out of the scripts, or just comment them out. In this case the values that are currently set, through the READOUT GUI, are used for the images name.

All reads made from a script will be automatically saved, with the exception of the one taken during the `ACQUISITION` option in the `OBSERVING_SETUP` part of the script.

For the observer's convenience dedicated templates for NIR observations are made available and example scripts (presented in Appendix D) can be found in `TemplateScripts/Examples` on the LUCIFER workstation.

The scripts are started by using the shell script `executeLUCIScript.sh` available at the prompt on any observer terminal. Scripts can be tested, as observer on the LUCIFER workstation, for correct syntax and structure whithout executing them, using the "–test" option =

```
executeLUCIScript.sh --test <scriptname>
```

The list below shows all possible parameters that can be used for a script. Comments to all possible entries are provided on the right handside. All parameters presented in the [*_OBSERVING_SETUP] can of course not be used all in one single script, especially since some are meant for "science" observations and others for calibration purposes.

```
[START_ARCHIVE_INFORMATION]
PARTNER                 =NOPARTNER              #AZ,COMMISSIONING,INAF,
                                                #LBTB,LBTO,LBTSDT,OSURC
PI_NAME                 =NOTSPECIFIED           #name of PI
PROP_ID                 =NOTSPECIFIED           #proposal ID string
[END_ARCHIVE_INFORMATION]

[START_INSTRUMENT_SETUP]
CAMERA                  =N3.75                  # N1.8|N3.75|N30
FILTER                  =Ks Br_gam              # name of one or two filters
GRATING_UNIT            =mirror                 # mirror|210_zJHK|200_H+K|150_Ks
CENTRAL_WAVELENGTH      =                       # value or leave blank
MASK                    =                       # IDxxx = mask id
                                                # NBxx  = cabinet position
                                                # leave blank for no mask
MASK_POSITION           =no_mask_in_use         # mask_in_fpu|mask_in_turnout|no_mask_in_use
FLEXURE_COMP            =on                     # enable flexure compensation
[END_INSTRUMENT_SETUP]


[START_TELESCOPE_SETUP]
TARGET_NAME             =test star              # any name or leave blank
TARGET_COORD            =05 02 50 20 40 50      # hh mm ss dd mm ss
GUIDE_NAME              =                       # any name or leave blank
GUIDE_COORD             =05 03 00 20 40 30      # hh mm ss dd mm ss
ROT_ANG                 =50                     # in degrees
ROT_MODE                =position               # position|parallactic|idle
TELESCOPE_MODE          =active                 # active|guide|track
[END_TELESCOPE_SETUP]


[START_READOUT_SETUP]
DIT                     =10                     # any positive value, no blanks allowed
NDIT                    =2                      # any positive value, no blanks allowed
NEXPO                   =2                      # as NDIT
ROE_MODE                =mer                    # o2dcr|o2scr|msr|mer (#reads)|lir
SAVE_MODE               =INTEGRATED             # integrated|cube|normal
SAVE_PATH               =/data/luci/20080911    # absolute save path
FILENAME                =script_                # root of the filenames
[END_READOUT_SETUP]


[START_OBSERVING_SETUP]
OFFSET_TYPE             =absolute               # relative|absolute
COORD_SYS               =DETXY                  # DETXY|RADEC
ACQUISITION             =20 20                  # wait after offset
JITTER                  =10 40.0                # jitter pattern with 10 exposures
                                                # a maximum offset distance of 40.0 arcsecs
OFFSET                  =10 00                  # offset from TARGET_COORD
OFFSET                  =10 00 45.6             # same as above with a rot angle offset of 45.6
POINTING                =06 40 40 21 23 30 06 40 59 21 24 00      # new pointing coords

FLAT                    =mer 10.0 5 10          # readout with DIT=3.0, NDIT=5, NEXPO=10
FLAT                    =mer 10.0 1 10 Ks clear N1.8 # specify additional instrument setup
FLAT                                            # readout using last readout setup
LAMP                    =Xe 10                  # turns on the Xe lamp for 10 secs
LAMP                    =Xe                     # as above but with automatic calculation
                                                # of the lamp activation time

DARK                    =o2dcr 60.0 5 10        # indicate DARK instead of FLAT
FLUSH_DETECTOR                                  # executes a flush readout of the detector
                                                # no parameters, no images are saved
```

```
[END_OBSERVING_SETUP]
```

Notes on script

- Archive information

  - Entries for `PI_NAME` & `PROP_ID` are entirely free
  - Entries for `PARTNER` are restricted to the following list:
    AZ,COMMISSIONING,INAF,LBTB,LBTO,LBTSDT,OSURC
    Multiple partners must be separated by a comma (,). Invalid partner names will cause the script to fail when it is read.
  - When any of the three parameters is missing in a script, the default value (as indicated in the above example) for this missing parameter is used.
  - Archive information set in scripts is used for all frames that are taken while the script is running, overriding any information that is set from the ReadoutManager GUI. While a script that contains archive information is running, the ReadoutManager GUI shows this information in red text color, as shown in Fig. 26.

  Archive Info   Partner:'LBTSDT', PI:'Anne Observer', PropID:'Proposal ID from script'

  Figure 26: Archive info section in the ReadoutManager GUI when a script is running

  - As soon as the script is finished the old information set in the GUI is used (and displayed) again for files that are saved from the GUI.
  - When a script without archiving information is running, the current values set from the GUI are written into the FITS headers.

- Instrument set_up

  - In the filter parameter, two filters can be set. Use this option to put crossed filters for acquisition on bright objects. Two filters from the same filter wheel cannot be set together! Possible crossed filters combinations for acquisition: HeI + z for a $\sim$ 7 mag. extinction, OH_1060 + z for a $\sim$ 3.9 mag. extinction, HeI + J for a $\sim$ 2.35 mag. extinction and P_gam + J for a $\sim$ 0.8 mag. extinction. Of course set_up like Br_gam + Ks are possible but provide a much lower extinction factor.
  - The flexure compensation flag should in principle always be set to "on". For short photometric standard or telluric stars observations, this can be left to off.

- Telescope set_up

  - Presets in active mode request that you provide a guide star, otherwise the preset will fail
  - Presets in track mode do not require a guide star but for the case no guide star information is present in the telescope set_up buffer (e.g. at the beginning of the night), provide as guide star coordinates the coord. of your target. A track mode preset will park the probe but the telescope software is anyway awaiting a full list of parameters - including the guide star information.

- READOUT set_up

  - NDIT is the number of reads (DIT) that will be performed at a given position. For NDIT > 1 the "SAVE_MODE" must be integrated.
  - If you want to save more than one image per position, then set this with NEXPO, which is the number of exposures of integration DIT×NDIT that wil be performed at the current position.

- If you decide to have NDIT >1 and "SAVE_MODE"= normal, note that all your NDIT images will be saved individually but only at the end of the NDIT reads and will all have one and the same fitsheader.

- The total number of frames you will get is defined as (Number of offsets defined in Observing set_up) * NEXPO is you are in integrated mode with NDIT> 1 or (Number of offsets defined in Observing set_up) * NEXPO * NDIT if data are saved in normal mode.

- Observing set_up

  - After a spectroscopic acquisition, the "OFFSET_TYPE" **has** to be relative, otherwise you loose the centering of your object behind the mask.

  - There is not automatic return to origin position at the end of the scripts (except you set your offsets accordingly)

  - The "ACQUISITION" command makes a read (as defined in Readout set_up) but does not save it. This command is useful for spectroscopic acquisition since it pauses the script till you are satisfied to continue (= you are finished with your alignment).

  - "jitter" creates a random generated jitter pattern to take (as defined in the example before) 10 images (=10 offsets), within a maximum (radial) distance of $40''$.

  - The syntax of the command is: $\Delta X/\Delta RA$ (arcseconds) $\Delta Y/\Delta DEC$ (arcseconds) ΔPA (degree)

  - The "pointing" command allows to make huge offsets but still remain in closed active loop since you have to provide the coordinates of a new guide star. Note however that the position angle cannot be changed between the two pointing positions.

  - "FLAT", "LAMP" & "DARK" are used for calibration purposes and should be set in separate scripts independant of the 'science' script.

  - "FLAT" is used only to take skyflats. It has to be set together with an instrument set_up and a readout mode set_up. NEXPO is used to define how many frames will be saved.

  - "LAMP" is used to take calibrations with the calibration unit. The script automatically takes frames with the lamp off first then the lamp on. If only the lamp name is given (e.g. LAMP =Xe), the activation time for the lamp will be calculated automatically from the readout setup (DIT, NDIT, NEXPO). Alternatively, the time the lamp should remain on can be set explicitly by specifying it as a second parameter (LAMP =Xe 10.0). To calculate the "lamp on" time manually use NEXPO*[NDIT*(DIT+2sec)+(NDIT-1)*5], where 2 sec is the readout time for the o2dcr mode (lamp calibrations in mer mode are rare since the integration time has to be short) and 5 the time to save a fitsfile. If NDIT>1, the save_mode has to be integrated.
  NOTE: The calibration unit has to be "IN" position, otherwise the script will abort when a "LAMP" script is started.

  - "DARK" is used to take dark frames. Should you wish to save darks in Normal or Integrated mode, so should you set two scripts separately.

  - "FLUSH_DETECTOR" performs 11 minutes of detector (short) reads. It is recommended to use this between your dark scripts to "clean" the detector. Similarly at the end of your dark script, please run the "clean" script, which is available in the Template-Scripts/Examples on the lucifer machine.

7.5   Target Acquisition

Target **acquisition** is needed mostly uniquely for spectroscopic acquisitions and **has to be set in a script separately from the science script**. Under given special circumstances, in imaging mode, one may wish to refine the "pointing" on a given science field; but normally no acquisition is needed for this observing mode.

7.5.1 Imaging

When wishing to perform deep imaging and thus many new presets may be needed, it might be good to check the field on the "acquisition" image before starting a script. This is easily done by performing a quick manual read of the detector. It sometimes directly shows an obvious shift in position of your field corresponding to the fact that the guide star found by the guider did not correspond to the one you selected. In principle, if that "automatically" found other guide star is suitable for guiding and the centering is not important for you, you can continue like this. Bear in mind however that this is a strong indication that a (telescope) pointing correction is needed.

7.5.2 Spectroscopy

The steps involved in a spectroscopic acquisition are:

- Preset the telescope to the new position

- While this is happening move the mask to the FPU

- Once guiding is started, take a through slit image with short exposure time & save it

- Move the mask to the `turnout` position via the "Mask_to_turnout" command in the MOS panel

- Once the collimation of the telescope is finished, take an acquisition image of the field of interest

- Center your object behind the mask using the SkyCat display

- Make a read from the Readout Manager GUI and check your alignment (in the SkyCat display), take a through slit image

- Once satisfied with the alignment, start your spectroscopic script that includes the instrument setup (mask in FPU, grating in position, ...)

When performing an acquisition before deep spectroscopic observations, avoid saturating the detector and thus creating persistance effects. Should the acquisition image contain bright stars, it is recommended to perform a number of short detector reads (DIT=2sec) with the 'blind' filters for a minute or two before starting the long integrations.

The details of the alignment procedure differ a bit depending if only long slit or multi-object spectroscopy is to be done, as detailed hereafter.

Long Slit Spectroscopy
    Long slit acquisition is easy: you wish to put one or more objects behind the long slit. For a single object, a simple offset will be enough, in case of two or more aligned objects to be put behind the mask, you may wish to adjust the position angle slightly.

The through slit image is needed as reference to move the object to the correct position. Once this image has been saved, put it as `Bias image` in skycat (option reacheable from the `File` pull down menu - top left of the panel) and subtract it from the acquisition image. Then use the *Telescope Control* GUI Shift image & rotate image buttons. If a rotation is needed, apply it first and then shift the object as needed.

The Shift Image button opens a new panel which leads the user through the procedure:

1. Click in the Skycat GUI to define the reference position and

2. click in the Skycat GUI to define the new position.

In detail: First of all, the image on which you want to do the measurements has to be opened in Skycat. Then click "yes" in the option panel. Now choose the reference object (star) in Skycat, click on it (pick object) and wait for a second or two. Skycat performs a 2D-Gauss fitting on the object. Once finished, click on the position where the reference point should be moved to (center of slit). Again, Skycat will make a fit and the calculated offset needed will appear on the *Telescope Control* GUI under the *Offset Telescope* area in the X,Y textfield within few seconds. Pressing the small COMMIT button located below will trigger the telescope offsetting.

The ROTATE IMAGE button opens a similar pop-up window as in the case of SHIFT IMAGE. The steps to follow are actually the same, except that a rotation offset will then be provided instead of a displacement offset.

Careful: If a non-zero rotation offset angle exists in the PA entry of the "Offset Telescope" area of the *Telescope Control* GUI, this will always be applied! Thus when offsetting after a rotation correction, make sure to set this value to zero before commiting your set-up.

Blind offset acquisition is feasible via scripts. The acquisition procedure is the same as described above but on a nearby "bright" star. At the end of the alignment procedure, the offset onto your science target will be performed ==> you preset onto the reference star and provide the offset to move from the reference star to the faint target. An example of script on how to do this is given here. The Acquisition option, allows to have a read of the telescope automatically performed (but no image saved from the script) once the collimation of the telescope has been reached. Then the script pauses as long as you do not explicitly tells it to continue. This "paused" time is then used to perform the alignment on the reference star. Once this is finished, let the script continue (& finish): it performs the blind offset and takes an image.

```
[START_INSTRUMENT_SETUP]
CAMERA                  =N3.75
FILTER                  =blind K
GRATING_UNIT            =mirror
MASK                    =NB4
MASK_POSITION           =mask_in_fpu
FLEXURE_COMP            =off
[END_INSTRUMENT_SETUP]


[START_TELESCOPE_SETUP]
TARGET_NAME             =MyTarget
TARGET_COORD            =11 22 33 +44 55 00.7
GUIDE_NAME              =GSC
GUIDE_COORD             =11 22 32.9 +44 55 01.2
ROT_ANG                 =12.5
ROT_MODE                =position
TELESCOPE_MODE          =active
[END_TELESCOPE_SETUP]


[START_READOUT_SETUP]
DIT                     =0
NDIT                    =30
NEXPO                    =1
ROE_MODE                =o2dcr
SAVE_MODE               =NORMAL
[END_READOUT_SETUP]


[START_OBSERVING_SETUP]
OFFSET_TYPE             =relative
COORD_SYS=RADEC
ACQUISITION             = 0 0
OFFSET                  =-26.61 98.34  # The offset to get centered on your faint source
[END_OBSERVING_SETUP]
```

Multi-object Spectroscopy
     The acquisition on custom made MOS mask happens as follow:

1. Put the mask in the focal plane and take a through mask image

2. Use the MOS Acquisition GUI and skycat to identify a reference point (small pinhole 'slit' which is present at the top of in any MOS mask)

3. Move the mask in Turnout and take an image of the field

4. Use the MOS Acquisition GUI and skycat to identify the reference stars used for the alignment

5. Calculate the transform to align the mask and commit the needed offsets (translation and rotation) to the telescope

6. Check the alignment was successful (either by repeating the last 3 steps or directly by checking in the through mask image, assuming "bright" enough objects are easily recognisable through the mask in 1 or 2 minute(s)).

Details of the different steps:

- Step 2

  - Press on the MOS ACQU button on the Telescope Control GUI (Fig. 21) to open the GUI needed for the alignment.

  - In the MOS ACQUISITION GUI (Fig. 27), select the camera used to take the through mask and press USE LMS FILE FOR REF. STARS
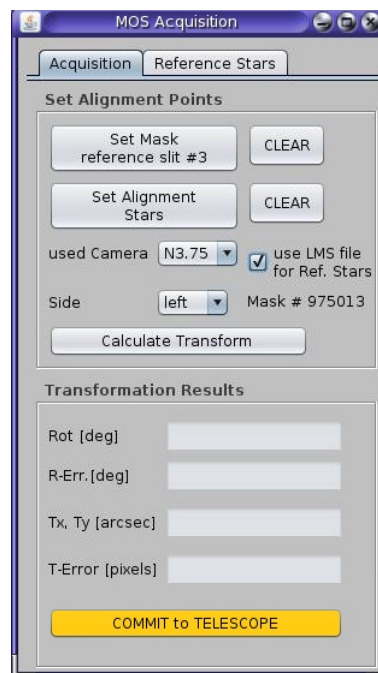
Figure 27: The LUCIFER MOS Acquisition GUI.

  - Check that the mask number that appears corresponds to the the Mask ID that can be read on the through mask image (Fig. 28)

  - Press SET MASK REFERENCE SLIT #3. This opens a first informative GUI (Fig. 29)

  - the through mask image is displayed in skycat, another pop-up (Fig. 30) provides further information on how to proceed

  - Once a "pick object" has been performed on the fits image, a new pop-up window (Fig. 31) conclude that part of the procedure.

Figure 28: Through mask image, where the mask ID (or number) is readable.

Figure 29: Pop-up window that appears when setting the mask reference (or the reference stars).
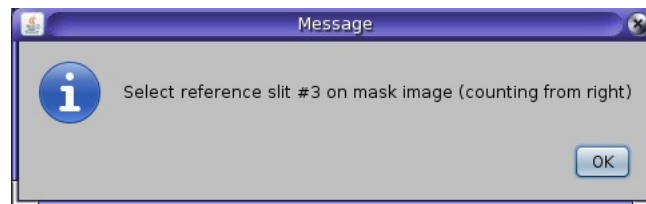
Figure 30: Pop-up window indicating how to select the reference slit #3.
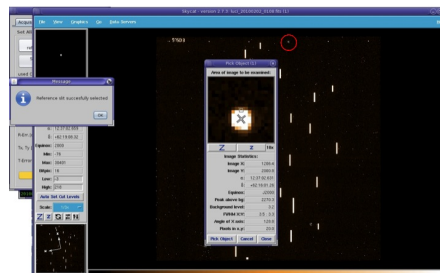
Figure 31: This figure shows the pop-up window that concludes the selection of the reference slit # 3 (indicated by the red circle) as well as the proper selection of that "pinhole slit".

- – If the above described steps have been done properly, in the MOS ACQUISITION GUI, the SET MASK REFERENCE SLIT #3 will turn yellow (Fig. 32 left) and the REFERENCE STARS subsection shows now the coordinates of the reference stars as well as the expected (x,y) positions of these stars on the detector (Fig. 32 right).

- • Step 4

  - – The saved image of the field has appeared on skycat. Should your obect be too faint for an easy identification, so apply a small offset (e.g. DETXY relative (5,5) in telescope GUI) and take another image. Use the first image taken as background in skycat and the last image as the positive one for the stars identification.
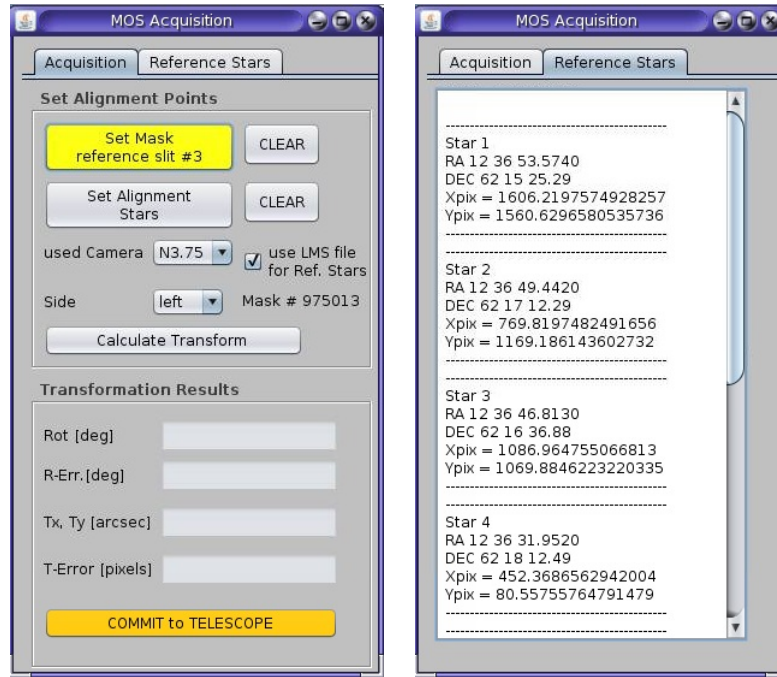
Figure 32: MOS Acquisition panel after selection of the reference slit #3.

- Press the button SET ALIGNMENT STARS in the MOS ACQUISITION GUI (Fig. 27)

- This opens a pop-up window identical to Fig. 29. Once the images are properly displayed, press YES.

- After that the identification of the reference stars start. A pop-up appears with the number of the reference star, its coordinates and estimated (x,y) position on the LUCIFER image. Use this information to identify your star. Careful, you have to press "OK" before performing a "pick object" on the star. After pressing OK the expected region where the reference star should be located is marked with a rectangle. Now you have to perform the pick object on the star. A good idea is to press "return" on the pop-up window while keeping the mouse on the star to be selected. Make sure to properly pick the object (well centered), use the "Z" or "z" buttons in the pick-up window to zoom in/out. After the pick object has been performed by the software (this can take a few seconds) a pop-up window (Fig. 33) asks if you want to continue with the next star or try the pick object on the currently selected reference star again in case you are not happy with the fit.

- Once all reference stars have been selected, a pop-up window similar to Fig. 31 will appear and conclude that part of the acquisition process. The corresponding SET ALIGMENT STARS button of the MOS Acquisition panel will turn yellow.

- Step 5

  - Press CALCULATE TRANSFORM on the MOS Acquisition GUI

  - If you are satisfied with the identification of the reference stars, then press OK. That will perform the calculation of the needed offsets based on all stars. If however, either a star was not found or you wish to remove one or more stars from your selection (e.g. because too faint), then give the number of that reference star in the pop-up panel before pressing OK. This calculation can be repeated as often as wished. For a well prepared mask the errors should be smaller tehn 0.5 pixels.

NOTE: Three "selections" are needed before you can "cancel" further star selection and thus "abort the process to e.g. restart it, by simply pressing CLEAR next to the SET ALIGNMENT STARS in the MOS Acquisition GUI.
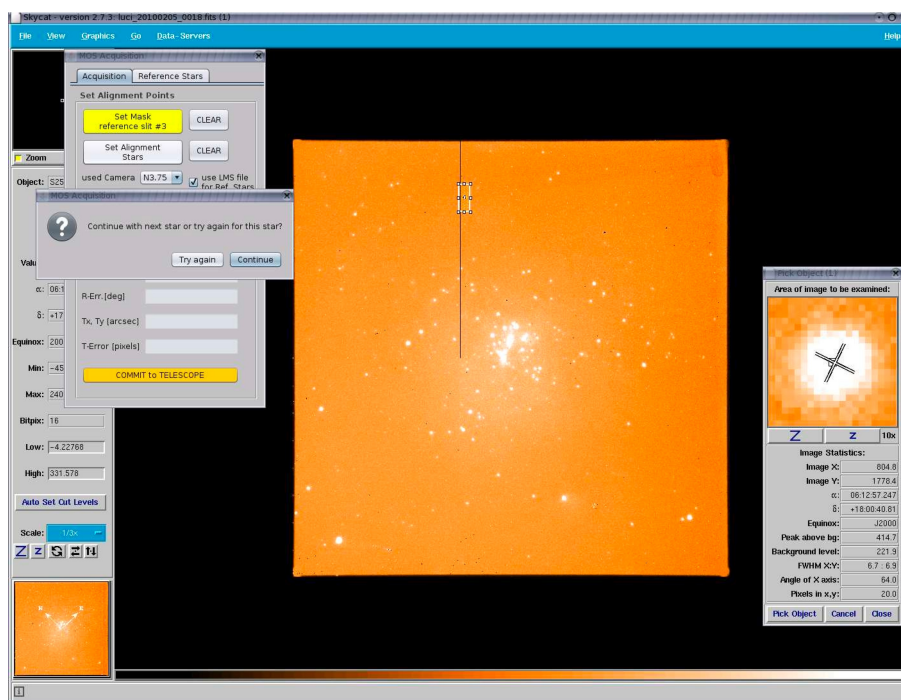
Figure 33: This figure shows the pop-up window asking if you wish to reselect the reference you just "picked", as well as the rectangle indicating where to find the star.

References

[TRANSA] http://unagi.gps.caltech.edu/notes/bfats2002/

[Rousselot et al.] 1999, A&A 354, p 1134

A Example of fits header

General fits header information

```
SIMPLE  =                     T
BITPIX  =                    32
NAXIS   =                     2
NAXIS1  =                  2048
NAXIS2  =                  2048
COMMENT =
BSCALE  =                   1.0
BZERO   =                   0.0
COMMENT =
COMMENT =
COMMENT =
COMMENT =
```

Time information

```
MJD-OBS =      55137.05830264 / Modified julian date 'days' of observation end
DATE-OBS= '2009-11-02T01:23:57.3480'/ UT-date of observation end
DATE    = '2009-11-02T01:23:58.1050'/ UT-date of file creation
UT      =           5037.3480 / '01:23:57.3480' UTC (sec) at EOread
LST     =          75016.640000 / local siderial time: 20:50:16 (EOread)

ORIGIN  = 'Mount Graham, MGIO, Arizona'
OBSERVER= 'master'
TELESCOP= 'LBT'
FRATIO  = 'F/15'
INSTRUME= 'Lucifer'
OPTIC   = 'high res.'
```

Detector related information

```
ELECGAIN=            4.100000 / electrons/DN
ENOISE  =           12.000000 / electrons/read
ELECTRON= 'MPIA IR-ROelectronics Vers. 2'
STRT-INT=           4934.6013 / '01:22:14.6013' start integration (sec) (UT)
STOP-INT=           5037.3432 / '01:23:57.3432' stop integration (sec) (UT)
OBJECT  = 'FS29'
EXPO_NO =                2192 / exposure/read counter
FILENAME= 'luci_20091101_0001.fits'
TPLNAME = ''                  / macro/template name
TIMER0  =                1984 / milliseconds
TIMER1  =                3000 / milliseconds
TIMER2  =             1016029 / microseconds
PTIME   =                   2 / pixel-time-base index
READMODE= 'o2.double.corr.read'/ read cycle-type
IDLEMODE= 'break'             / idle to read transition
SAVEMODE= 'o2.double.corr.read'/ save cycle-type
CPAR1   =                   1 / cycle type parameter
ITIME   =            3.000000 / (on chip) integration time [secs]
CTIME   =            5.105992 / read-mode cycle time [secs]
```

```
CRATE    =                0.195848 / read-mode cycle rate [Hz]
HCOADDS  =                       1 / # of hardware coadds
PCOADDS  =                       1 / # of coadded plateaus/periods
SCOADDS  =                      20 / # of software coadds
NCOADDS  =                      20 / effective coadds (total)
EXPTIME  =               60.000000 / total integ. time [secs]
FRAMENUM=                       1 / INTEGRAL OF 20
SKYFRAME= 'unknown'
SAVEAREA= '[1:2048,1:2048]'
SOFTWARE= 'GEIRS Vers. hwplx-r251.sv9b-x04 (Sep 17 2008, 22:35:45)'
COMMENT = 'your comment'
```

WCS information

```
CRVAL1   =            328.08217135 /
CRVAL2   =              2.38875000 /
RA       =    '21:52:19.721123281'/ RA at MJD-OBS
DEC      =    '+02:23:19.542202486'/ DEC at MJD-OBS
RADECSYS=                   'FK5'/
CRPIX1   =             1014.060000 /
CRPIX2   =             1043.510000 /
SECPIX1  =               -0.120000 /
SECPIX2  =                0.120000 /
CDELT1   =              0.00003333 /
CDELT2   =              0.00003333 /
CTYPE1   =              'RA---TAN'/
CTYPE2   =              'DEC--TAN'/
CROTA1   =              315.000000 /
CROTA2   =              315.000000 /
CD1_1    =              0.00002357 /
CD1_2    =              0.00002357 /
CD2_1    =             -0.00002357 /
CD2_2    =              0.00002357 /
```

Telescope information

```
OBJRA    =           '21 52 25.3835'/ RA requested
OBJDEC   =           '+02 23 19.556'/ DEC requested
TELALT   =               56.203419 / LBT mount altitude at MJD-OBS
TELAZ    =              150.097107 / LBT mount azimuth at MJD-OBS
PARANGLE=                -24.5389 / Parallactic angle at start (deg)
POSANGLE=                 45.0000 / position angle at start (deg)
ROTANGLE=                437.4367 / rotator angle at start (deg)
M1-X     =               -0.272624 / X pos of PM
M1-Y     =               -1.975723 / Y pos of PM
M1-Z     =                1.568008 / Z pos of PM
M1RX     =               51.267850 / X rot of PM
M1RY     =              -13.041830 / Y rot of PM
M1RZ     =                0.000000 / Z roy of PM
M1CTEMP =                 8.549333 / temp of PM
M2-X     =               -7.010000 / X pos od SM
M2-Y     =               -3.879000 / Y pos of SM
M2-Z     =                0.000000 / Z pos of SM
M2RX     =              148.650000 / X rot of SM
M2RY     =              181.800000 / Y rot of SM
M2RZ     =                0.000000 / Z rot of SM
```

```
M2CTEMP =                    8.549333 / temp of SM
M3TIP   =                    0.000000 / tip of TM
M3TILT  =                    0.000000 / tilt of TM
M3PSTN  =                    0.000000 / position of TM
M3ZROT  =                    0.000000 / Z rot of TM
M3CTEMP =                    8.533334 / temp of TM
TTEMP201=                    8.291000 / telescope temp at sensor 201
TTEMP202=                    8.711000 / telescope temp at sensor 202
TTEMP203=                    8.845000 / telescope temp at sensor 203
TTEMP204=                    8.514000 / telescope temp at sensor 204
TTEMP205=                    8.765000 / telescope temp at sensor 205
TTEMP206=                    8.911000 / telescope temp at sensor 206
TTEMP207=                    8.722000 / telescope temp at sensor 207
TTEMP208=                    8.428000 / telescope temp at sensor 208
TTEMP209=                    8.889000 / telescope temp at sensor 209
TTEMP210=                    8.628000 / telescope temp at sensor 210
TTEMP301=                    8.896000 / telescope temp at sensor 301
TTEMP302=                    7.168000 / telescope temp at sensor 302
TTEMP303=                    8.686000 / telescope temp at sensor 303
TTEMP304=                    7.555000 / telescope temp at sensor 304
TTEMP305=                    8.238000 / telescope temp at sensor 305
TTEMP306=                    6.566000 / telescope temp at sensor 306
TTEMP307=                    8.711000 / telescope temp at sensor 307
TTEMP308=                    7.188000 / telescope temp at sensor 308
TTEMP309=                    8.645000 / telescope temp at sensor 309
TTEMP310=                    6.682000 / telescope temp at sensor 310
SMTTEMP =                    6.100000 / ambient temp SMT weather station
SMTPRES =                  693.559900 / pressure at SMT weather station
SMTHUM  =                   23.300000 / humidity at SMT weather station
SMTDWPT =                  -13.350290 / dewpoint at SMT weather station
LBTTEMP =                    0.000000 / ambient temp at LBT weather station
LBTPRES =                    0.000000 / pressure at LBT weather station
LBTHUM  =                    0.000000 / humidity LBT weather station
LBTDWPT =                    0.000000 / dewpoint LBT weather station
GUIRA   =              '21 52 36.538'/  RA of guide object
GUIDEC  =              '+02 25 52.21'/  DECS of guide object
```

Information about the status of the calibration lamps

```
STATLMP1=                      'OFF'/ Ne
STATLMP2=                      'OFF'/ Ar
STATLMP3=                      'OFF'/ Xe
STATLMP4=                      'OFF'/ HALO1
STATLMP5=                      'OFF'/ HALO2
STATLMP6=                      'OFF'/ HALO3
```

Temperature of electronics racks

```
RACKTEM1=                      292.82 / rack sensor 1 (I-Rack)
RACKLVL1=                       100.0 / output level channel 1
RACKTEM2=                      293.82 / rack sensor 2 (motion control electron
RACKLVL2=                       100.0 / output level channel 2
RACKTEM3=                      287.83 / rack sensor 3 (readout electronics)
RACKLVL3=                       100.0 / output level channel 3
RACKTEM4=                      284.06 / rack sensor 4 (ambient)
RACKLVL4=                    200004.0 / unused
```

```
RACKCLG =                               'ON'/ cooling of the electronics rack
```

Pressure and temperature of instrument

```
PRESSUR1=                    3.1200E-7 / mbar
PRESSUR2=                    2.2300E-5 / mbar
DETTEMP1=                        77.00 / input channel A (detector)
DETTEMP2=                        60.04 / input channel B (cold bench)
INSTEMP1=                        67.15 / sensor 1 (structure bottom)
INSTEMP2=                        72.35 / sensor 2 (focal plane unit)
INSTEMP3=                        69.98 / sensor 3 (getter unit)
INSTEMP4=                        70.19 / sensor 4 (structure top)
INSTEMP5=                        67.91 / sensor 5 (camera unit)
INSTEMP6=                        81.66 / sensor 6 (grating unit)
INSTEMP7=                        74.86 / sensor 7 (MOS unit)
INSTEMP8=                       505.00 / sensor 8 (MOS unit)
```

Instrument set-up

```
M4M1POS =                        -1313 / position of mirror 4 motor 1
M4M2POS =                          367 / position of mirror 4 motor 2
CAMPOS  =                            2 / position of camera unit
CAMNAME =                'N3.75 Camera'/ camera name
PIXSCALE=                      0.12000 / arcsec/pixel
INSFOCUS=                         -165 / detector focus (steps from reference)
FILTPOS1=                            3 / position of FW1
FILTER1 =                      'clear'/ name of filter in FW1
FILTPOS2=                           14 / position of FW2
FILTER2 =                          'K'/ name of filter in FW2
GRATPOS =                            2 / position of the grating unit
GRATNAME=                     'mirror'/ name of the grating unit element
GRATVOLT=                     -3.85069 / tilt voltage
GRATWLEN=                   'not used'/ central wavelength (microns)
GRATORDE=                   'not used'/ used grating diffraction order
GRATLOOP=                       'OPEN'/ regulation loop status
MOSPOS  =           'no mask in use'/ position of the MOS unit
MASKSLOT=                    'unknown'/ number of the used mask
MASKID  =                    'unknown'/ ID of the used mask
MASKNAME=                    'unknown'/ description of the used mask
PVSTATUS=           'PUPIL_VIEWER_OUT'/ position of pupil viewer
LMS_INFO=         'No LMS information'/
DATATYPE=                    'SCIENCE'/
END
```
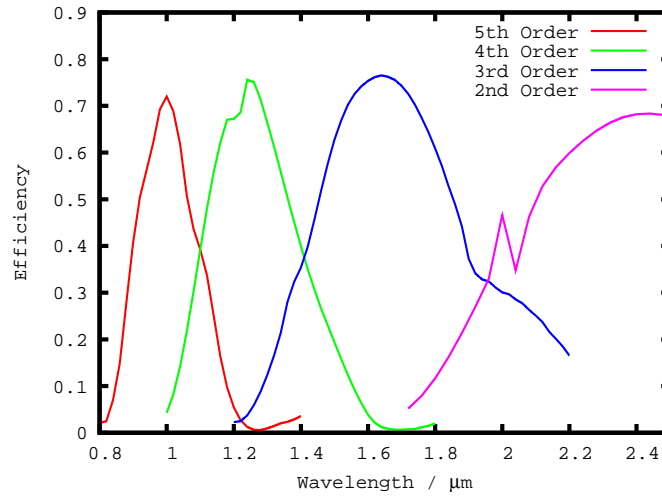
B   Grating Efficiencies

Figure 34: The efficiency of the 210_zJHK grating versus the wavelength, in Littrow configuration. The different orders (5th - 2nd) of the grating are color coded.
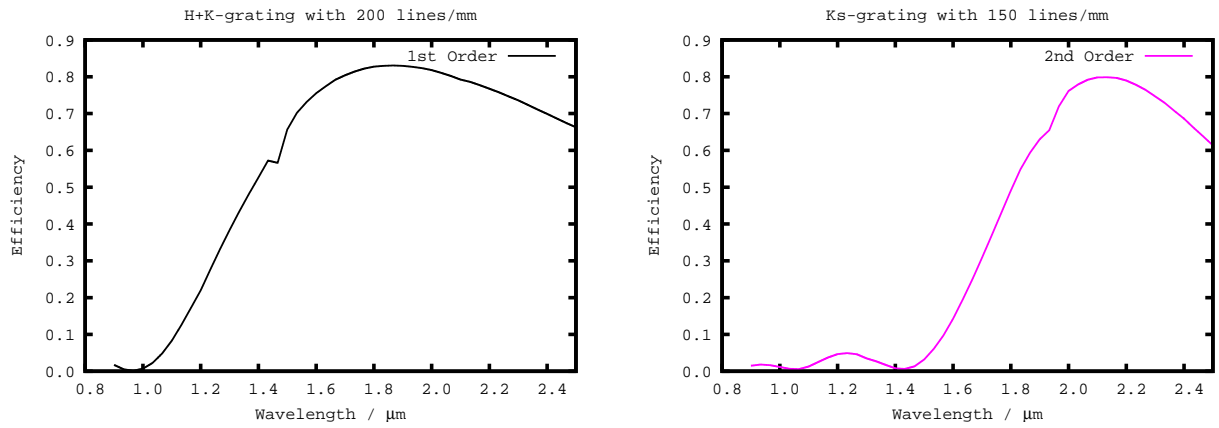

Figure 35: Grating efficiency versus wavelength, in Littrow configuration: 200_H+K grating left, 150_Ks right.

C   Additional filter information

Table 19: Specifications for the filters.

Operating Temperature	60 K, i.e. $-213°$C
Blocking	OD4 from 0.8 to 3.0,μ
Thickness	7.0 ± 0.5 mm
Quality	$\lambda/2$ per inch, image quality
	suppression of internal ghosts
AOI	normal incidence ($0°$), in parallel beam
AR Coating	on outer surface(s) if applicable
Wedge	≤ 30 arcsec
Clear Aperture	66 x 80 mm (62 x 62 mm)
Size	71 x 85 mm, (67 x 67 mm) +0.0 mm -0.2 mm
Peak Transmission	$\geq 80\%$, ($\geq 65\%$)
Tolerance CWL	$\pm$ 10% (10%) of FWHM
Tolerance FWHM	$\pm$ 5% (10%) of FWHM

Table 20: Characteristics of the current **LUCIFER#2** filters.

Name	LUCIFER	λ_C/μm	FWHM/μm	τ_{peak}	$\tau_{average}$
z (ED034-2)	2	0.965	0.196	93.8 %	89.9 %
J (ED044)	2	1.250	0.301	90.9 %	87.1 %
H (ED024)	2	1.651	0.291	92.1 %	85.4 %
K (ED059)	2	2.199	0.408	92.1 %	84.5 %
K_s (ED046-1)	2	2.161	0.270	91.7 %	85.9 %
Order Separation ED763-2	2	1.953	0.998	95.7 %	88.3 %
Brackett-γ (ED477-2)	2	2.171	0.023	83.1 %	82.0 %
FeII (ED468-2)	2	1.645	0.018	91.1 %	88.0 %
H2 (ED469-2)	2	2.127	0.023	83.9 %	82.0 %
Paschen-β (ED476-3)	2	1.284	0.013	85.8 %	85.2 %
Paschen-γ (ED467-4)	2	1.096	0.010	70.4 %	68.9 %

C.1   Filter Curves
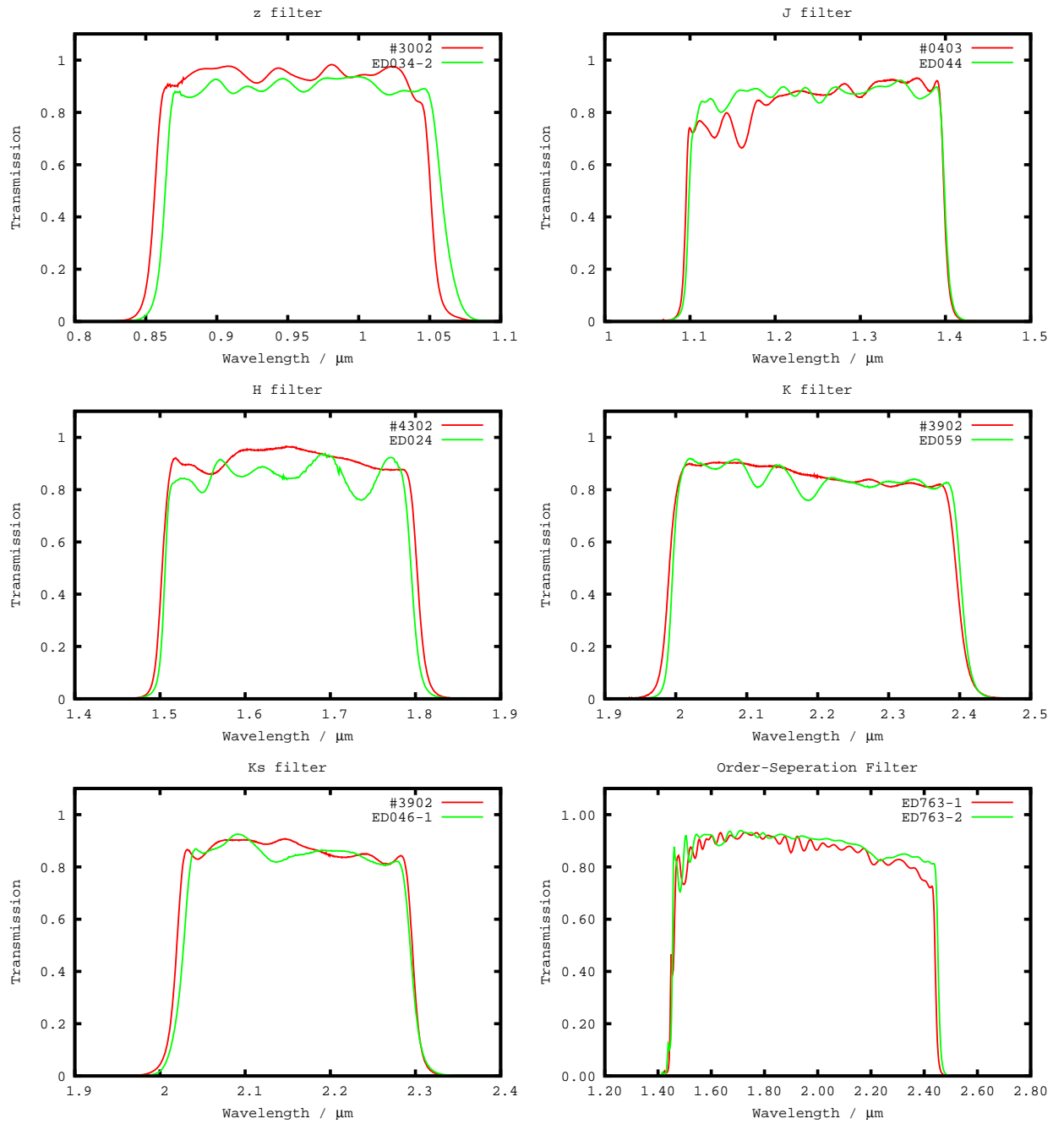
C.1.1   Broad Band

Figure 36: Filter curves for broad-band filters. (Red = filters installed in LUCIFER1)
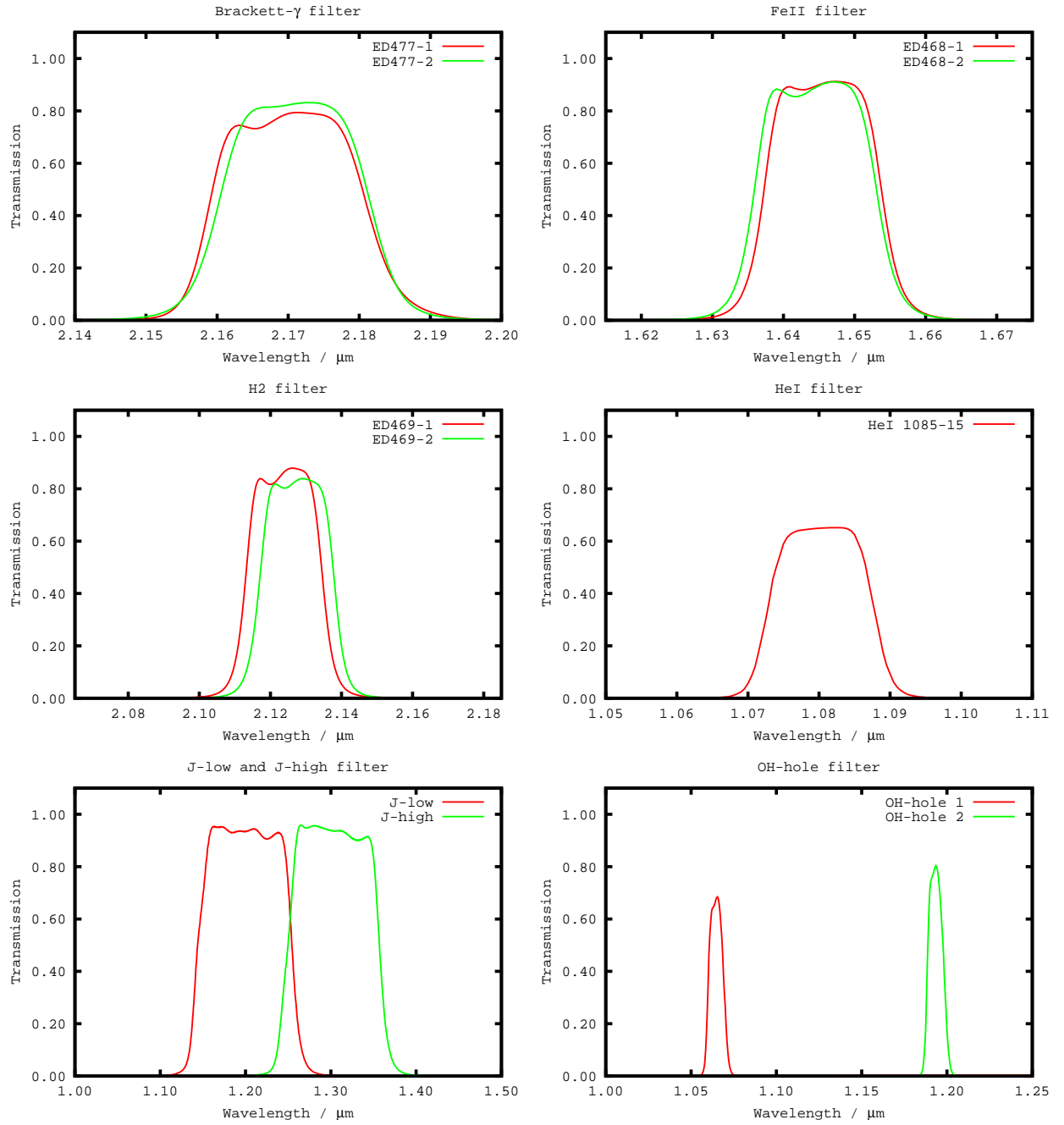
C.1.2 Narrow Band

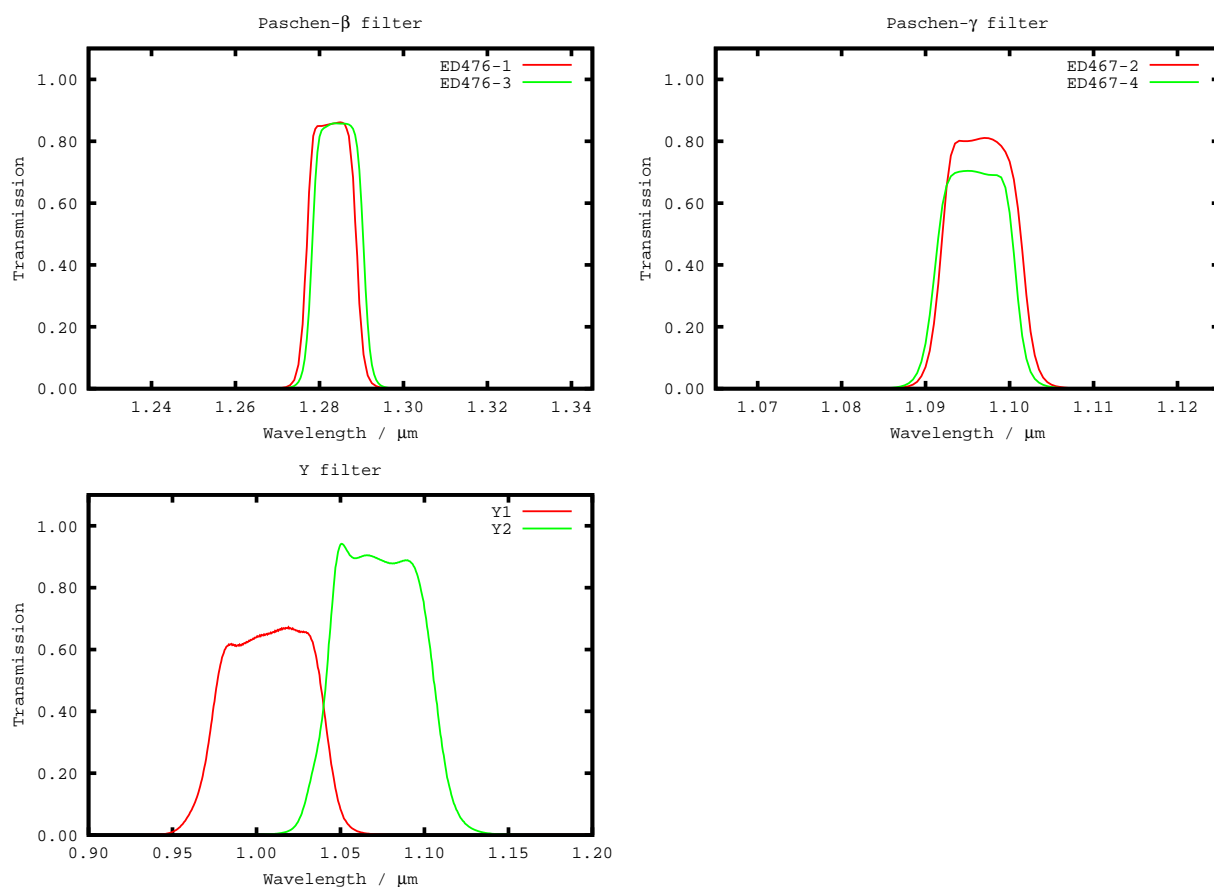Figure 37: Narrow band filter curves (Part 1).

Figure 38: Narrow band filter curves (Part 2). If not otherwise specified, the red curves are the filters present in LUCIFER1. When specified, e.g. for Y1/Y2, then both filters are present in LUCIFER1.

D   Example of Scripts

Template used for taking photometric standards

Note: the mask parameters were set from a previous use of this template and are simply commented out.

```
[START_TELESCOPE_SETUP]
TARGET_NAME    =FS 106
TARGET_COORD   =01 49 46.95 +48 37 53.4
GUIDE_NAME     =GS_R13.91_d4.31_pos230.96
GUIDE_COORD    =01 50 07.139 +48 40 37.50
ROT_ANG        = 45
ROT_MODE       =position
TELESCOPE_MODE =active
[END_TELESCOPE_SETUP]


[START_INSTRUMENT_SETUP]
CAMERA                 =N3.75
FILTER                 =K
GRATING_UNIT           =mirror
CENTRAL_WAVELENGTH     =
#MASK                   =NB4
#MASK_POSITION          =mask_in_turnout
FLEXURE_COMP           =OFF
[END_INSTRUMENT_SETUP]


[START_READOUT_SETUP]
DIT                    =2
NDIT                   =30
NEXPO                  =1
ROE_MODE               =o2dcr
SAVE_MODE              =integrated
#SAVE_PATH              =/data/luci/YYYYMMDD/
FILENAME               =luci_YYYYMMDD_Std_
[END_READOUT_SETUP]


[START_OBSERVING_SETUP]
COORD_SYS              = DETXY
OFFSET_TYPE            = relative
OFFSET                 =45 45
OFFSET                 =00 -90
OFFSET                 =-90 0
OFFSET                 =00 90
OFFSET                 =45 -45
[END_OBSERVING_SETUP]
```

Example of Jitter imaging template taking 3 images per position (NEXPO), performing 10 offsets with a maximum offset size of $90''$ between positions

```
[START_INSTRUMENT_SETUP]
CAMERA                 =N3.75
FILTER                 =Ks
GRATING_UNIT           =mirror
MASK_POSITION          =no_mask_in_use
[END_INSTRUMENT_SETUP]
```

```
[START_TELESCOPE_SETUP]
TARGET_NAME             =YourFavorite
TARGET_COORD            =00 11 22.33 33 44 55.66
GUIDE_NAME              =SelectedGS
GUIDE_COORD             =00 11 20.7 33 44 06.77
ROT_ANG                 =88
ROT_MODE                =position
TELESCOPE_MODE          =active
[END_TELESCOPE_SETUP]


[START_READOUT_SETUP]
DIT                     =10
NDIT                    =1
NEXPO                   =6
ROE_MODE                =o2dcr
SAVE_MODE               =NORMAL
[END_READOUT_SETUP]


[START_OBSERVING_SETUP]
OFFSET_TYPE             =absolute
COORD_SYS               =DETXY
JITTER                  =10 90.0
[END_OBSERVING_SETUP]
```

Example of spectroscopic scripts

Acquisition template including blind offset

```
[START_INSTRUMENT_SETUP]
CAMERA                  =N3.75
FILTER                  =Br_gam K
GRATING_UNIT            =mirror
MASK                    =NB4
MASK_POSITION           =mask_in_turnout
FLEXURE_COMP            =off
[END_INSTRUMENT_SETUP]


[START_TELESCOPE_SETUP]
TARGET_NAME             =MyTarget
TARGET_COORD            =11 22 33 +44 55 00.7
GUIDE_NAME              =GSC
GUIDE_COORD             =11 22 32.9 +44 55 01.2
ROT_ANG                 =12.5
ROT_MODE                =position
TELESCOPE_MODE          =active
[END_TELESCOPE_SETUP]


[START_READOUT_SETUP]
DIT                     =0
NDIT                    =30
NEXPO                   =1
ROE_MODE                =o2dcr
SAVE_MODE               =NORMAL
[END_READOUT_SETUP]
```

```
[START_OBSERVING_SETUP]
OFFSET_TYPE            =relative
COORD_SYS             =RADEC
ACQUISITION           = 0 0
OFFSET                =-26.61 98.34
[END_OBSERVING_SETUP]
```

Spectroscopic "science" template with nodding along the slit

```
[START_INSTRUMENT_SETUP]
CAMERA                =N1.8
FILTER                =OrderSep
GRATING_UNIT          =200_H+K
CENTRAL_WAVELENGTH    =2.106
MASK                  =NB4
MASK_POSITION         =mask_in_fpu
FLEXURE_COMP          =on
[END_INSTRUMENT_SETUP]
```

```
[START_READOUT_SETUP]
DIT                   =100
NDIT                  =3
NEXPO                 =1
ROE_MODE              =mer
SAVE_MODE             =INTEGRATED
[END_READOUT_SETUP]
```

```
[START_OBSERVING_SETUP]
OFFSET_TYPE           =relative
COORD_SYS             =DETXY
OFFSET                =00 00
OFFSET                =00 30
OFFSET                =00 -60
[END_OBSERVING_SETUP]
```

Spectroscopic lamp calibration using the calibration unit.

```
[START_INSTRUMENT_SETUP]
CAMERA                =N1.8
FILTER                =K
GRATING_UNIT          =210_zJHK
CENTRAL_WAVELENGTH    =2.106
MASK                  =NB4
MASK_POSITION         =mask_in_fpu
FLEXURE_COMP          =off
[END_INSTRUMENT_SETUP]
```

```
[START_READOUT_SETUP]
DIT                   =5
NDIT                  =1
NEXPO                 =1
ROE_MODE              =o2dcr
SAVE_MODE             =normal
```

```
FILENAME                  =luci_YYYYMMDD_Calib_
[END_READOUT_SETUP]


[START_OBSERVING_SETUP]
LAMP                      =Ar 10
LAMP                      =Xe 10
LAMP                      =HALO2 10
[END_OBSERVING_SETUP]
```

Example of sky flat script

```
[START_INSTRUMENT_SETUP]
CAMERA                    =N3.75
FILTER                    =HeI
GRATING_UNIT              =mirror
CENTRAL_WAVELENGTH        =
MASK                      =
MASK_POSITION             =no_mask_in_use
FLEXURE_COMP              =off
[END_INSTRUMENT_SETUP]


[START_READOUT_SETUP]
DIT                       =4
NDIT                      =1
NEXPO                     =5
ROE_MODE                  =o2dcr
SAVE_MODE                 =normal
SAVE_PATH                 =/data/luci/YYYYMMDD
FILENAME                  =luci_YYYYMMDD_Flat_
[END_READOUT_SETUP]


[START_OBSERVING_SETUP]
FLAT
[END_OBSERVING_SETUP]
```

Examples of script to take dark calibrations in the morning

```
[START_READOUT_SETUP]
DIT                       =2
NDIT                      =1
NEXPO                     =5
ROE_MODE                  =o2dcr
SAVE_MODE                 =normal
SAVE_PATH                 =/data/luci/20091104
FILENAME                  =luci_YYYYMMDD_Dark_
[END_READOUT_SETUP]

[START_OBSERVING_SETUP]
DARK
DARK                      =o2dcr 3 1 5
DARK                      =o2dcr 6 1 5
DARK                      =o2dcr 15 1 5
DARK                      =o2dcr 60 1 5
DARK                      =o2dcr 120 1 5
```

```
DARK                       =o2dcr 600 1 3
FLUSH_DETECTOR
DARK                       =mer 600 1 2
FLUSH_DETECTOR
[END_OBSERVING_SETUP]


[START_READOUT_SETUP]
DIT                        =2
NDIT                       =30
NEXPO                      =3
ROE_MODE                   =o2dcr
SAVE_MODE                  =integrated
SAVE_PATH                  =/data/luci/YYYYMMDD
FILENAME                   =luci_YYYYMMDD_Dark_
[END_READOUT_SETUP]

[START_OBSERVING_SETUP]
DARK
DARK                       =o2dcr 3 20 3
DARK                       =o2dcr 4 15 3
DARK                       =o2dcr 5 3 5
DARK                       =o2dcr 10 3 5
DARK                       =o2dcr 20 3 3
DARK                       =o2dcr 30 4 3
FLUSH_DETECTOR
DARK                       =mer 300 2 3
[END_OBSERVING_SETUP]
```